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(54) **ABRASIVE ROTARY TOOL WITH ABRASIVE AGGLOMERATES**

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B24D 3/18 (2006.01)
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CPC ***B24D 3/10*** (2013.01); ***B24B 5/313*** (2013.01); ***B24B 5/48*** (2013.01); ***B24B 9/065*** (2013.01);
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(58) **Field of Classification Search**
CPC ... B24D 3/10; B24D 3/18; B24D 3/28; B24D 11/02; B24D 11/04; B24D 13/12;
(Continued)

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(57) **ABSTRACT**

An abrasive rotary tool includes a tool shank defining an axis of rotation for the rotary tool, and an abrasive external working surface. The abrasive external working surface includes a resin, and a plurality of porous ceramic abrasive composites dispersed in the resin, the porous ceramic abrasive composites including individual abrasive particles dispersed in a porous ceramic matrix. At least a portion of the porous ceramic matrix comprises glassy ceramic material. A
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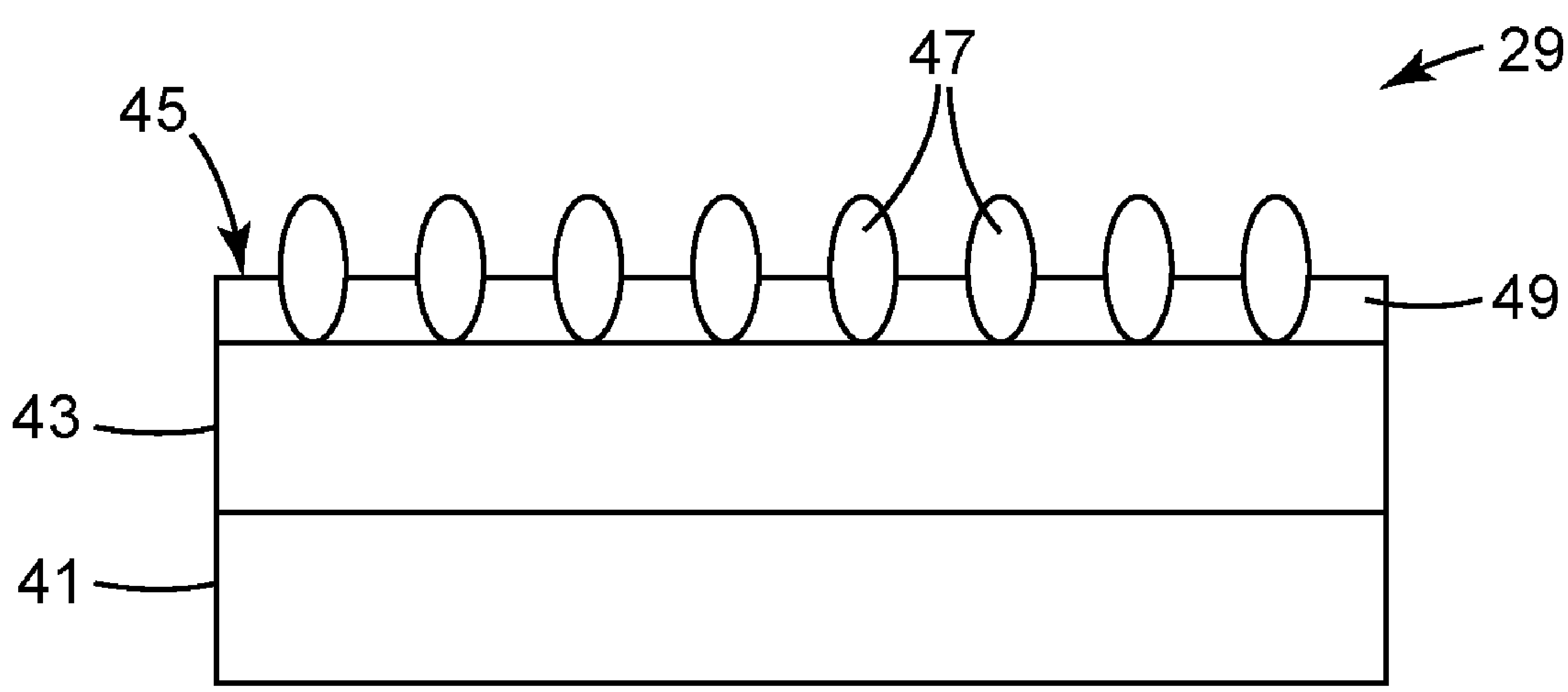

ratio of the average porous ceramic abrasive composite size to the average individual abrasive particle size is no greater than 15 to 1.

20 Claims, 7 Drawing Sheets

(51) **Int. Cl.**

B24D 11/02	(2006.01)
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B24D 11/04	(2006.01)
B24D 13/12	(2006.01)
B24D 13/14	(2006.01)
B24B 5/313	(2006.01)
B24B 5/48	(2006.01)
B24B 9/06	(2006.01)
B24B 9/10	(2006.01)

(52) **U.S. Cl.**
CPC ***B24B 9/10*** (2013.01); ***B24D 3/18*** (2013.01); ***B24D 3/28*** (2013.01); ***B24D 11/02*** (2013.01); ***B24D 11/04*** (2013.01); ***B24D 13/12*** (2013.01); ***B24D 13/142*** (2013.01); ***B24D 13/147*** (2013.01)

(58) **Field of Classification Search**
CPC B24D 13/142; B24D 13/147; B24B 5/48; B24B 5/313; B24B 9/065; B24B 9/10
See application file for complete search history.

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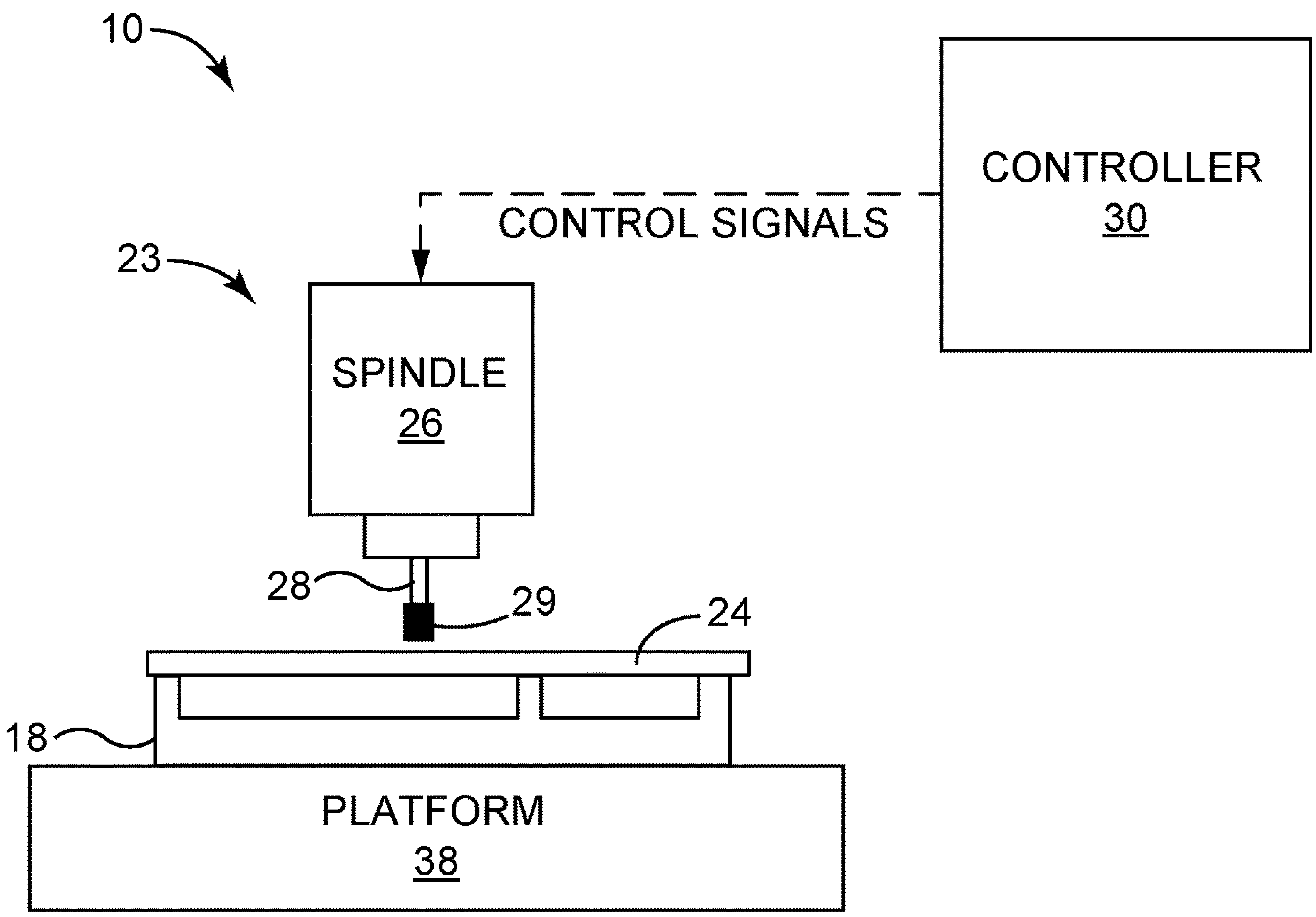

10
CONTROLLER
30
CONTROL SIGNALS
23
SPINDLE
26
28
29
24
18
PLATFORM
38

FIG. 1

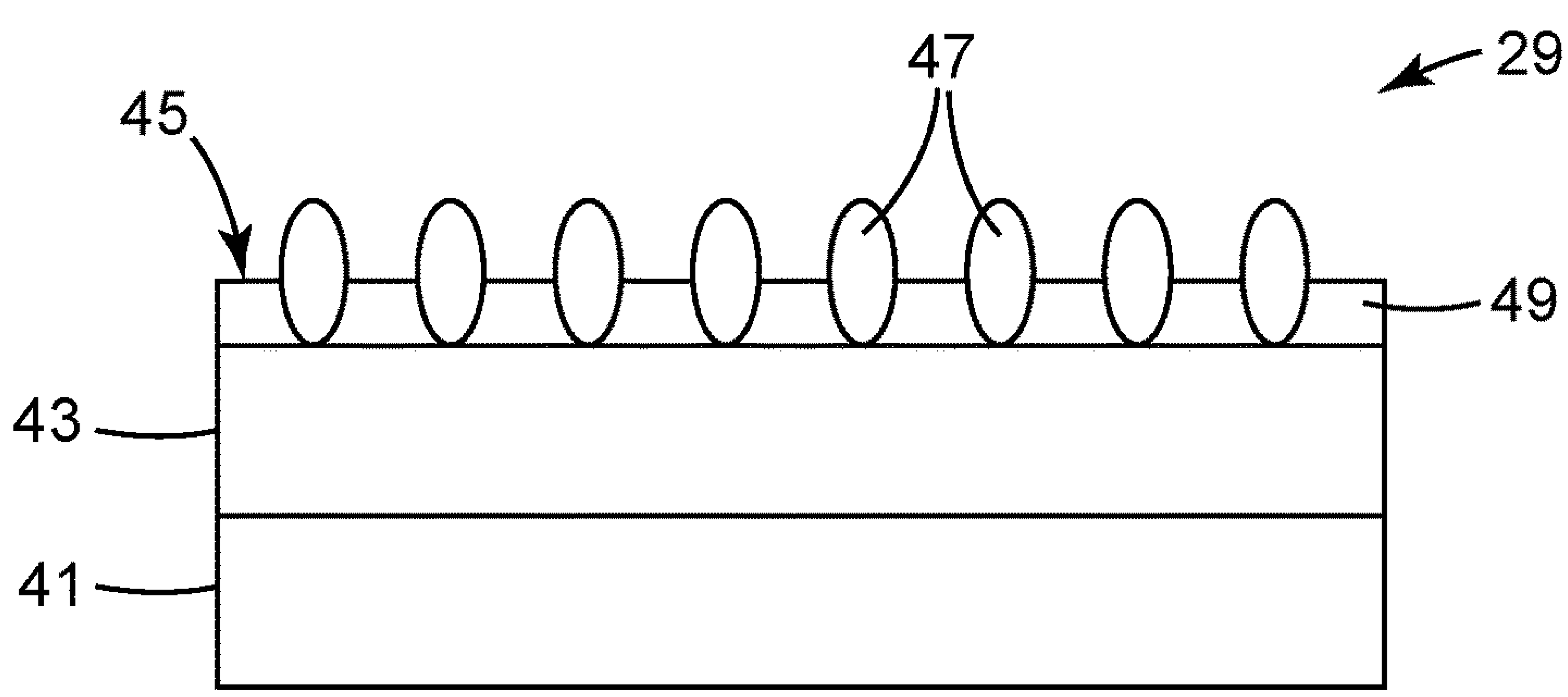

47
29
45
49
43
41

FIG. 1A

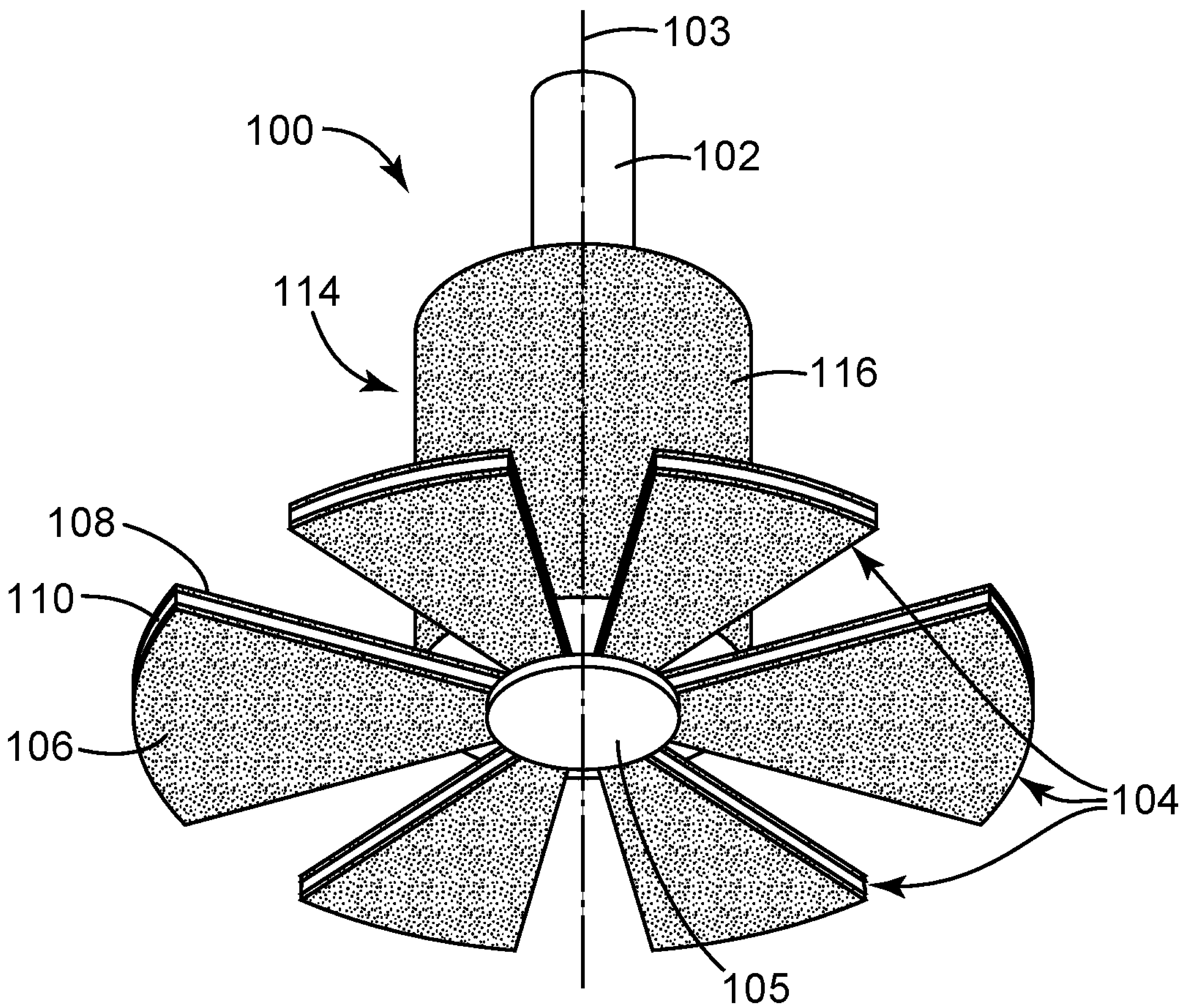
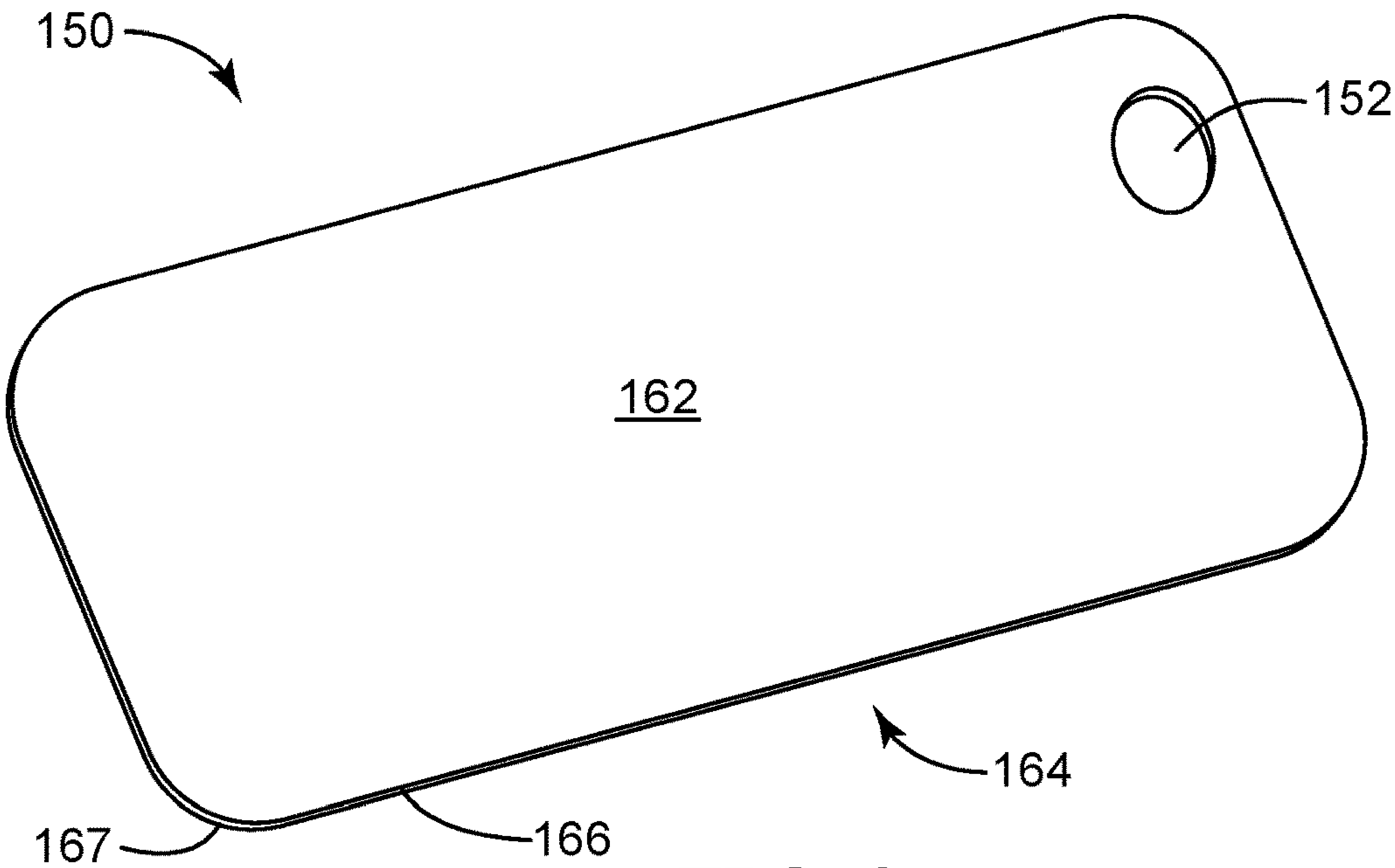


FIG. 2


150
152
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166

FIG. 3

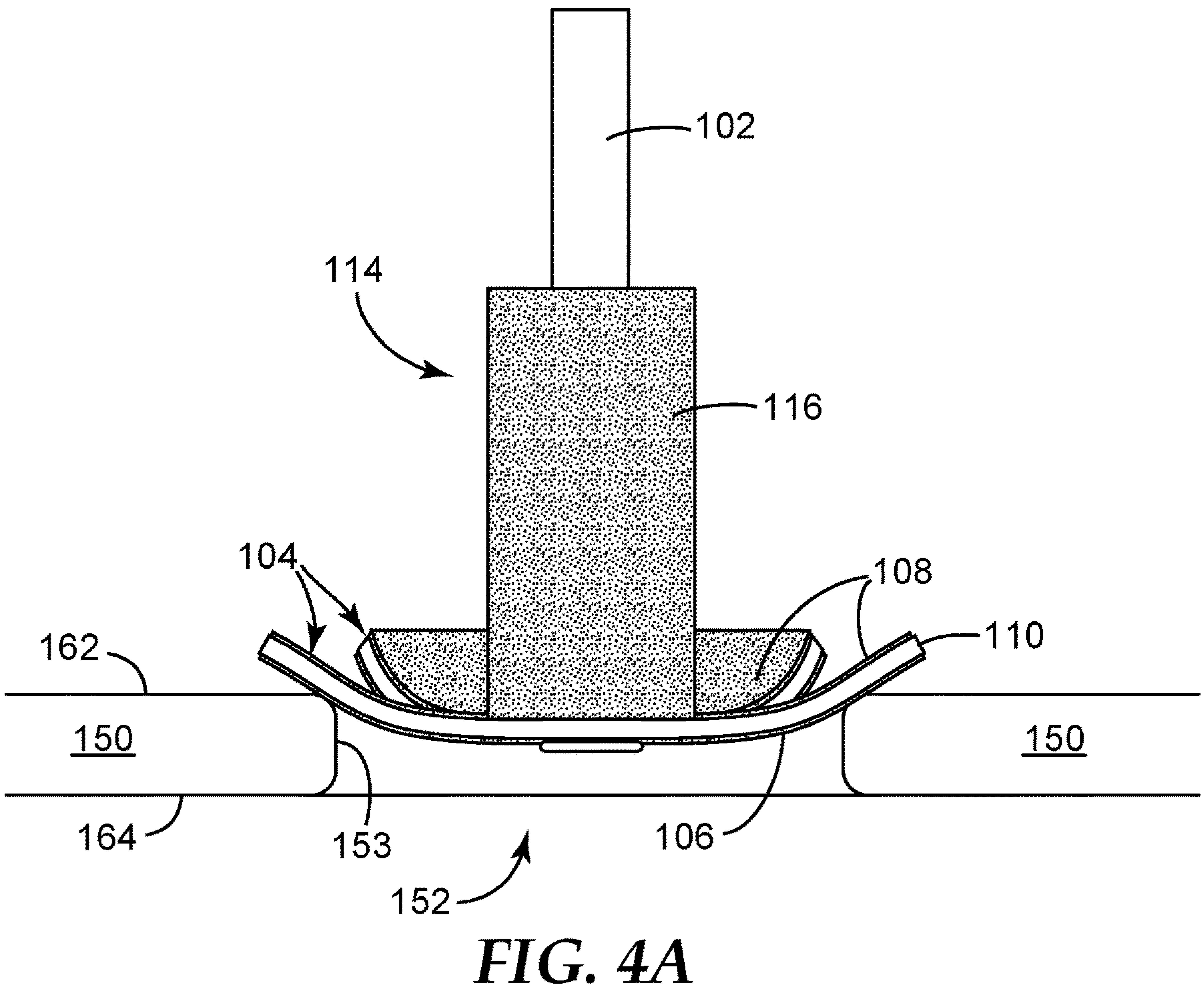
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FIG. 4A

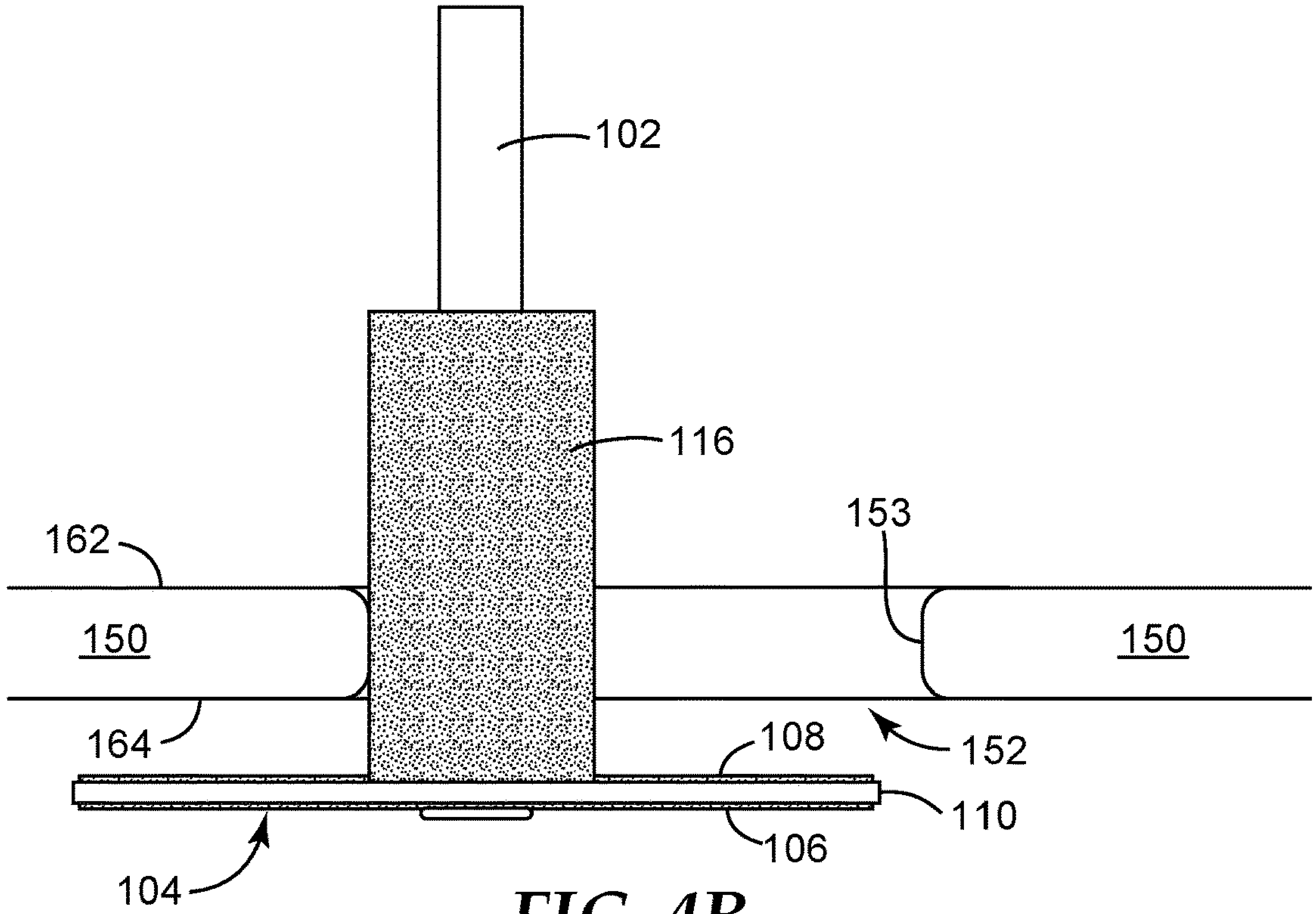
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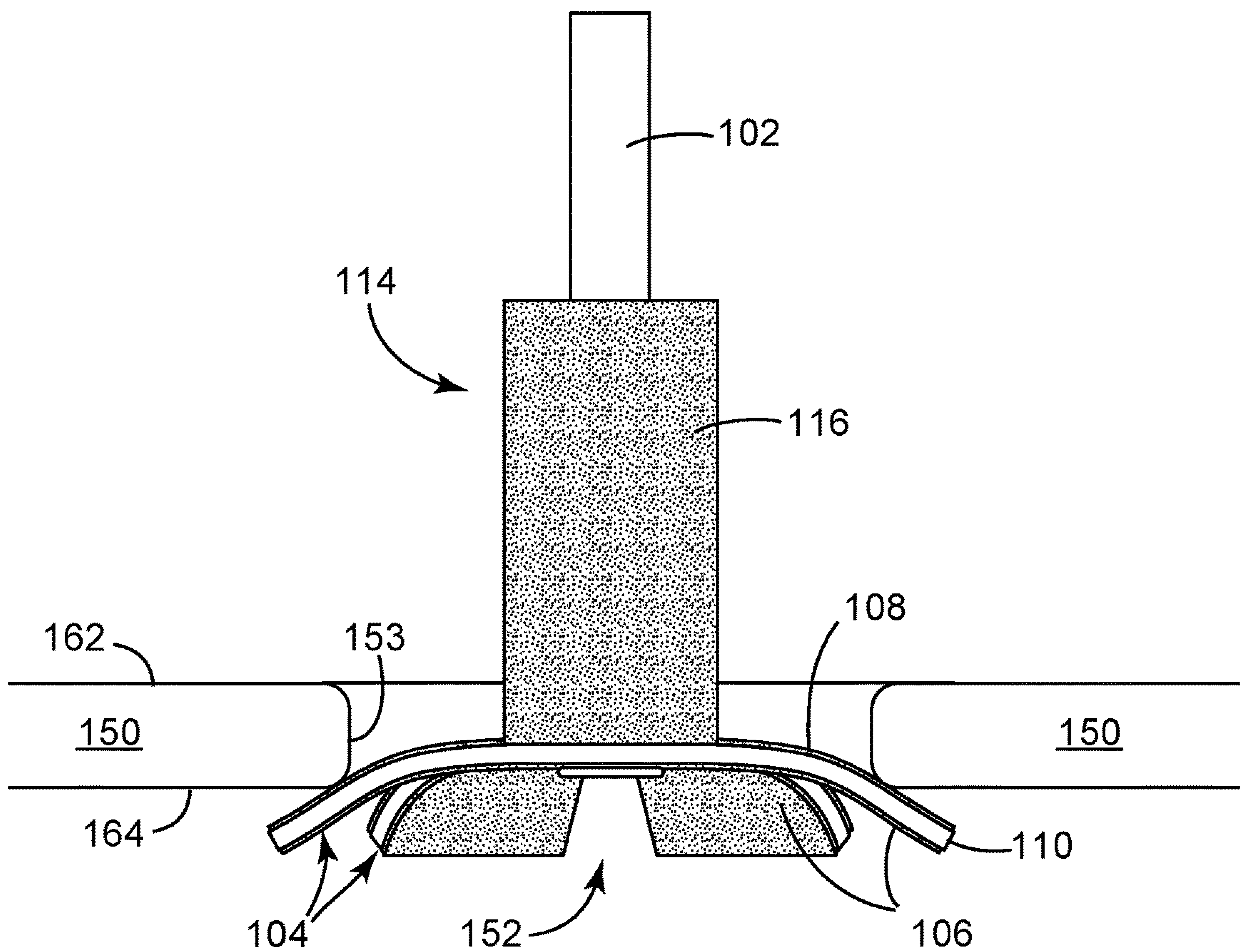
FIG. 4B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153
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150
164
110
104
152
106

FIG. 4C

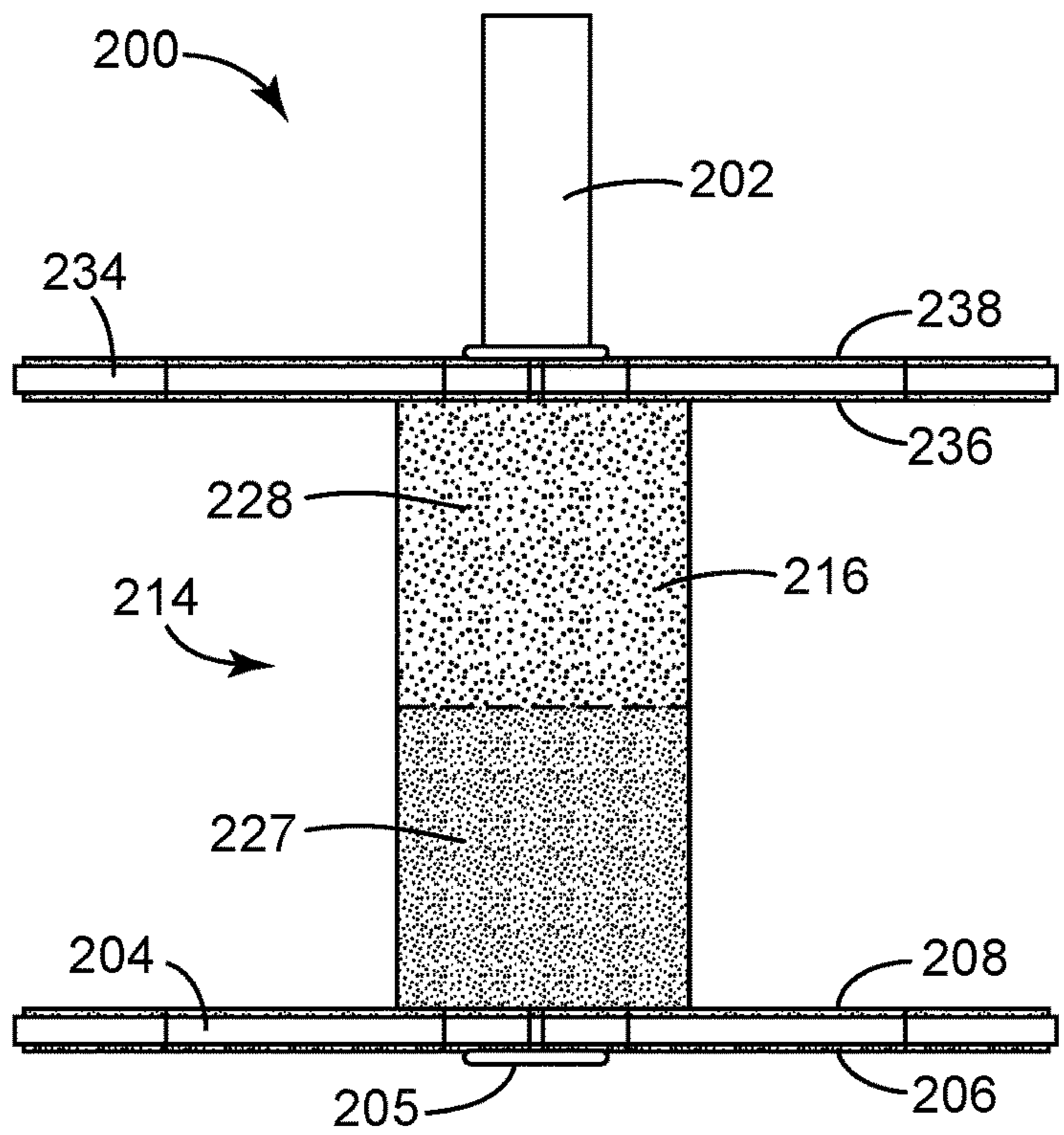

FIG. 5

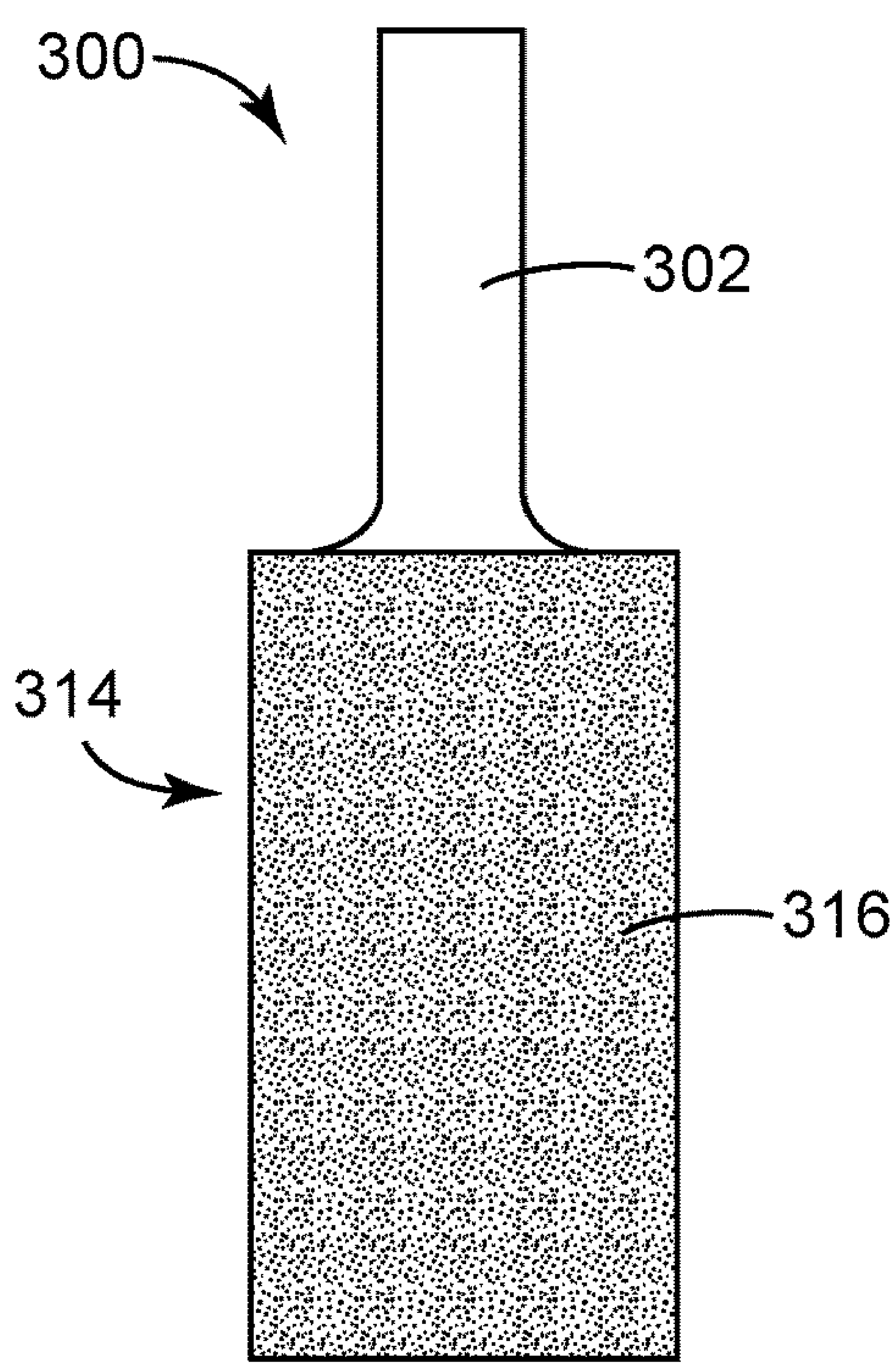

FIG. 6

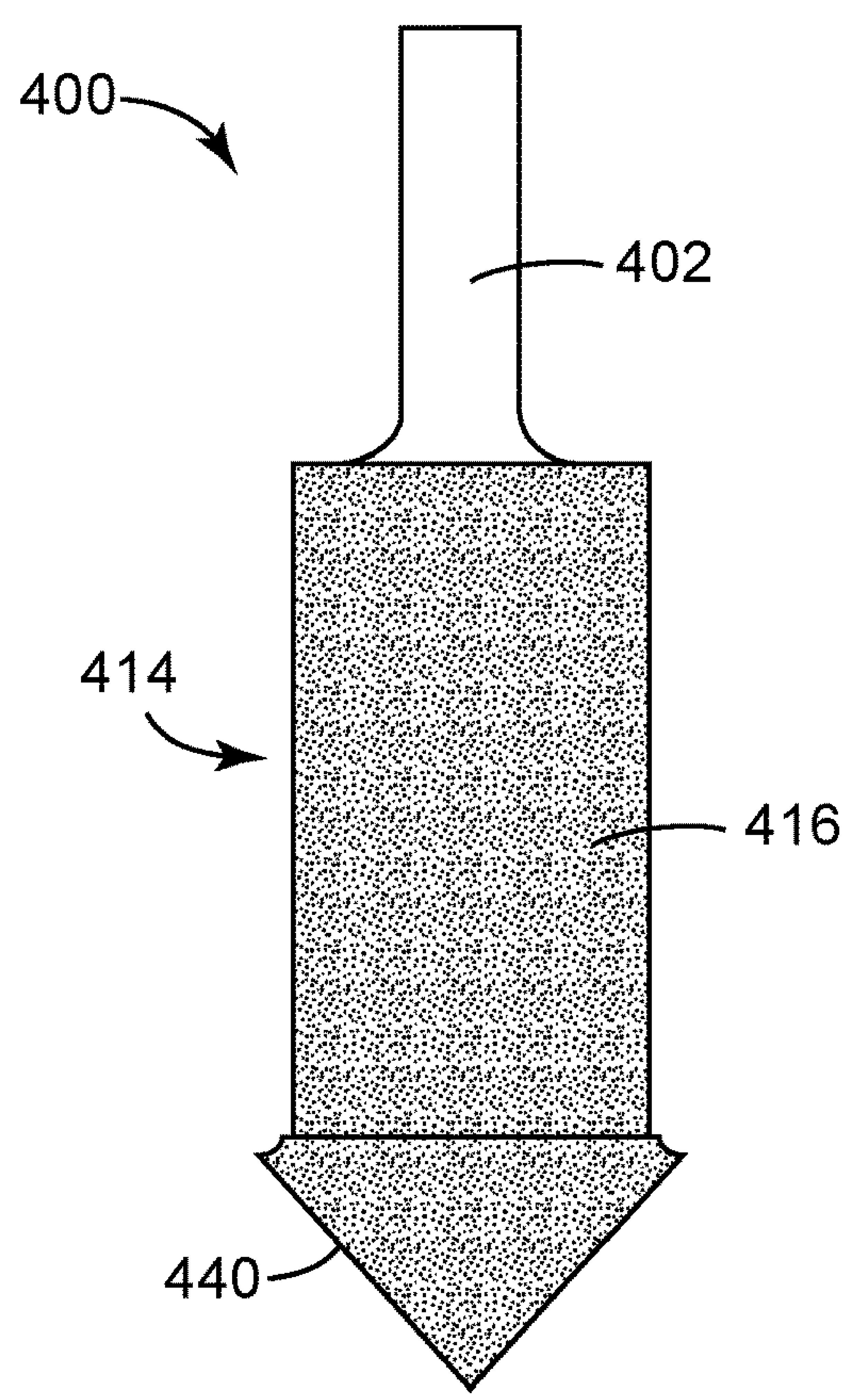

FIG. 7

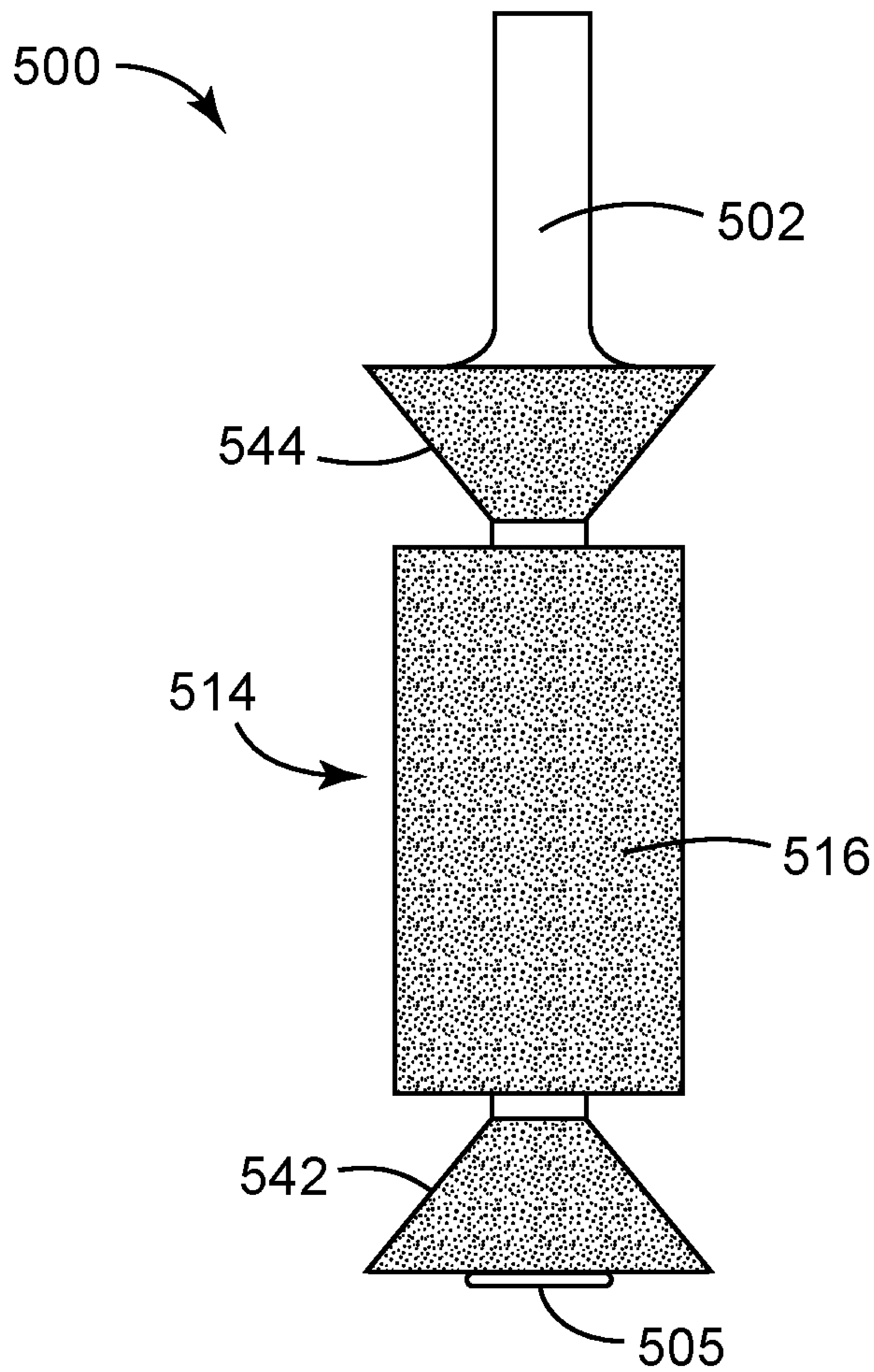

FIG. 8

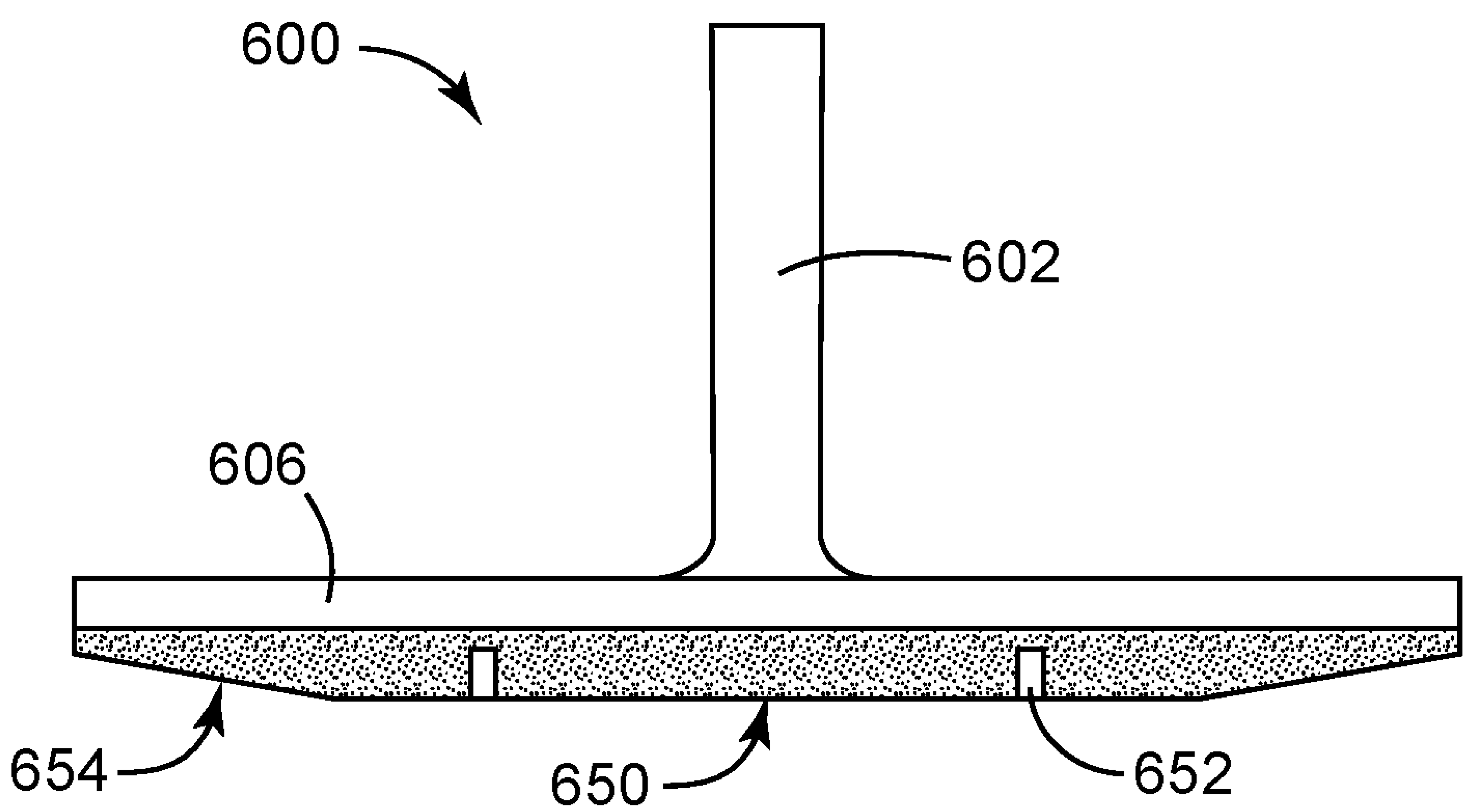

FIG. 9

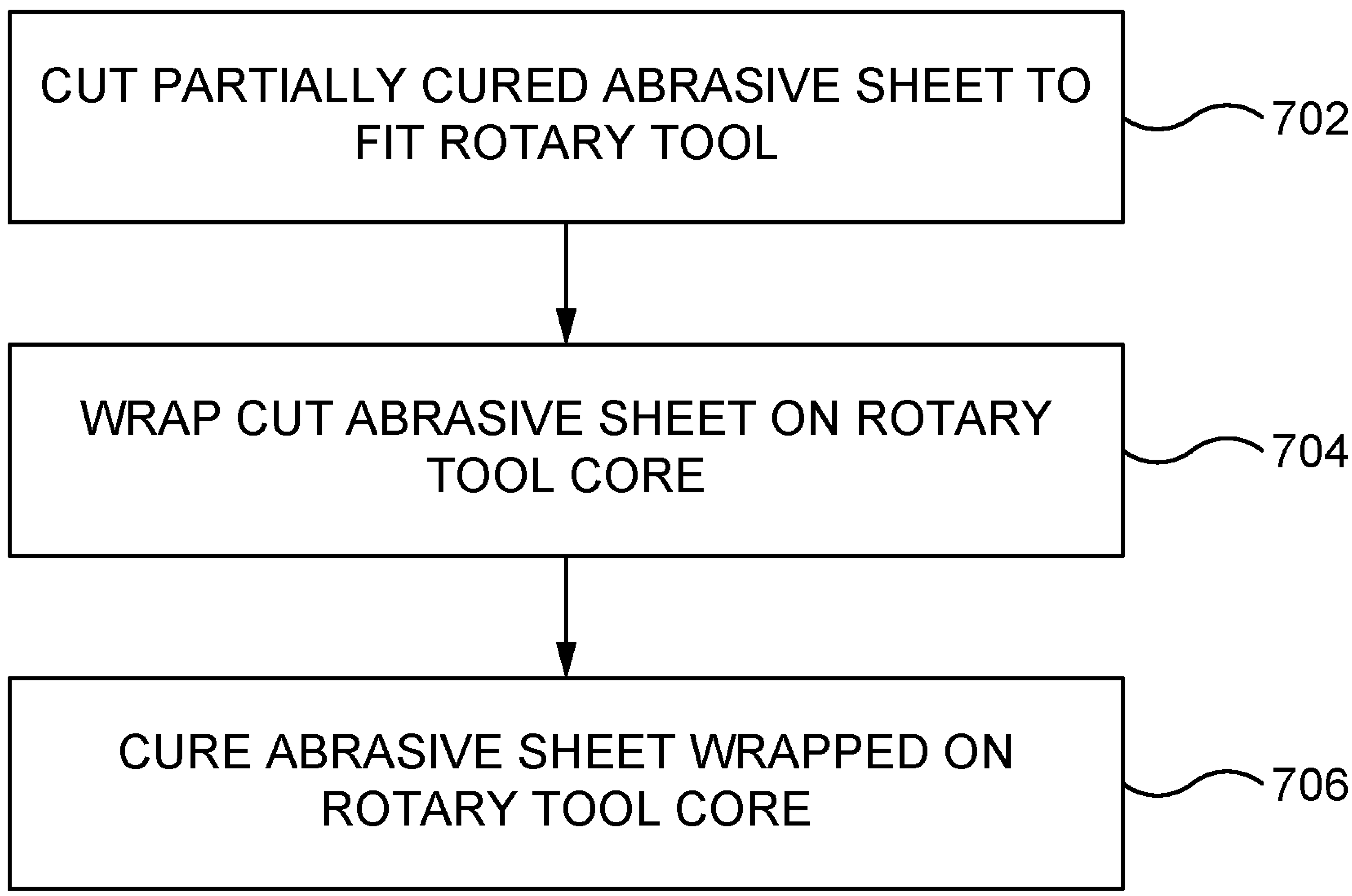
CUT PARTIALLY CURED ABRASIVE SHEET TO FIT ROTARY TOOL
702
WRAP CUT ABRASIVE SHEET ON ROTARY TOOL CORE
704
CURE ABRASIVE SHEET WRAPPED ON ROTARY TOOL CORE
706

FIG. 10

ABRASIVE ROTARY TOOL WITH ABRASIVE AGGLOMERATES

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a national stage filing under 35 U.S.C. 371 of PCT/US2016/050351, filed Sep. 6, 2016, which claims the benefit of U.S. Provisional Application No. 62/262,003, filed Dec. 2, 2015 and U.S. Provisional Application No. 62/215,640, filed Sep. 8, 2015, the disclosure of which is incorporated by reference in their entirety herein.

TECHNICAL FIELD

The invention relates to abrasives and abrasive tools.

BACKGROUND

Handheld electronics, such as touchscreen smartphones and tablets, often include a coverglass to provide durability and optical clarity for the devices. Production of coverglass may use computer numerical control (CNC) machining for consistency of features in the coverglass and high volume production. The edge finishing of the perimeter of a coverglass as well as machined features, such as holes, in the coverglass is important for strength and cosmetic appearance.

SUMMARY

This disclosure is directed to abrasives and abrasive tools. The disclosed techniques may be of particular usefulness for surface finishing, such as edge finishing or polishing after an edge grinding step as part of a coverglass manufacturing process.

In one example, this disclosure is directed to an abrasive rotary tool including a tool shank defining an axis of rotation for the rotary tool, and an abrasive external working surface. The abrasive external working surface includes a resin, and a plurality of porous ceramic abrasive composites dispersed in the resin, the porous ceramic abrasive composites comprising individual abrasive particles dispersed in a porous ceramic matrix. At least a portion of the porous ceramic matrix comprises glassy ceramic material. A ratio of the average porous ceramic abrasive composite size to the average individual abrasive particle size is no greater than 15 to 1.

In further example, this disclosure is directed to a method of finishing an edge of a partially-finished cover glass for an electronic device using the abrasive rotary tool of the preceding paragraph, the method comprising continuously the rotating abrasive rotary tool, and contacting the edge with the abrasive external working surface of the continuously rotating abrasive rotary tool to abrade the edge.

In another example, this disclosure is directed to abrasive rotary tool comprising a tool shank defining an axis of rotation for the rotary tool, and a flexible planar section positioned opposite the tool shank.

The flexible planar section forms a first abrasive external working surface on a first side of the flexible planar section, the first side of the flexible planar section facing generally away from the tool shank. The flexible planar section forms a second abrasive external working surface on a second side of the flexible planar section, the second side of the flexible planar section facing in the general direction of the tool shank. The flexible planar section facilitates abrading, with the first abrasive external working surface, a first corner adjacent to a first side of a workpiece across multiple angles relative to the axis of rotation for the rotary tool through bending of the flexible planar section when the first abrasive external working surface is applied to the first corner of the workpiece. The flexible planar section facilitates abrading, with the second abrasive external working surface, a second corner adjacent to a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece, across multiple angles relative to the axis of rotation for the rotary tool through bending of the flexible planar section when the second abrasive external working surface is applied to the second corner of the workpiece.

The details of one or more examples of this disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of this disclosure will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates a system for abrading a workpiece, such as a coverglass for an electronic device with a rotary abrasive tool.

FIG. **1**A illustrates a schematical cross-section of an abrasive article according to some embodiments of the present disclosure.

FIG. **2** illustrates an example rotary abrasive tool including a set of flexible flaps with an abrasive external surface that facilitates abrading an edge of a workpiece across multiple angles through bending of the flexible flaps.

FIG. **3** illustrates a partially-finished coverglass for an electronic device.

FIGS. **4**A-**4**C illustrate the rotary abrasive tool of FIG. **2** being used to abrade a partially-finished coverglass.

FIG. **5** illustrates an example rotary abrasive tool including two sets of flexible flaps with abrasive external surfaces, and the different flexible flaps may include different levels of abrasion.

FIG. **6** illustrates an example rotary abrasive tool including an abrasive external surface forming a cylindrical shape in coaxial alignment with the axis of rotation for the rotary tool.

FIG. **7** illustrates an example rotary abrasive tool including an abrasive external surface forming a cylindrical shape in coaxial alignment with the axis of rotation for the rotary tool and an angled surface including an abrasive external surface for abrading a beveled edge of the workpiece.

FIG. **8** illustrates an example rotary abrasive tool including a first abrasive external surface forming a cylindrical shape in coaxial alignment with the axis of rotation for the rotary tool, and first and second angled surfaces including abrasive external surfaces for abrading beveled edges of the workpiece.

FIG. **9** illustrates an example rotary abrasive tool including an abrasive external surface forming a planar surface perpendicular with the axis of rotation for the rotary tool.

FIG. **10** is a flowchart illustrating example techniques for manufacturing a rotary tool with an epoxy abrasive sheet.

DETAILED DESCRIPTION

Diamond abrasive tools may be used to improve the surface finish of perimeter edges and feature perimeter edges of a coverglass machining process. Such diamond abrasive tools include metal bonded diamond tools, such as plated, sintered and brazed metal bonded diamond tools. Metal bonded diamond tools may provide relatively high durability and effective cutting rates, but leave micro-cracks in the glass that are stress points that can be the initiation points for breakage, significantly reducing the strength of a finished coverglass below its potential facture resistance.

To improve the strength and/or appearance of coverglass, the edges can be polished following a grinding of machined edges, using, for example, a cerium oxide (CeO) slurry, to remove grinding and machining marks in the coverglass. However, such edge polishing can be lengthy for a coverglass, up to many hours in order to provide a desired surface finish for all edges of a coverglass. For example, polishing of a single coverglass many required steps to effectively polish all edges, including the perimeter, holes and corners. Polishing machines can be relatively large and expensive, and unique to the particular feature being polished. For this reason, production of coverglass in a manufacturing environment may include a number of parallel polishing lines, each including a number of polishing machines, in order to provide a desired production capacity of coverglass for the facility. Reducing processing time would allow an increase in the throughput of each polishing line.

In addition, polishing slurries may be inconsistent such that the polishing of a coverglass is not precisely predictable. Polishing may also cause an undesirable rounding of the corners following the relatively precise shaping provided by the grinding operations. Precise shaping requirements for coverglass may include simple shapes such as rounding, or precise bevel or chamfer or it may include more complex shapes such as a prescribed spline shape. In general, longer polishing provides an improved surface finish, but a greater rounding effect and less precision for the final dimensions of the coverglass. Reducing processing time to provide desired surface finish qualities of a coverglass may not only reduce production time, but may also provide more precise dimensional control for the production of coverglass. The abrasive compounds and tools disclosed herein may facilitate such a reduction in processing time for the production of coverglass.

FIG. **1** illustrates system **10**, which includes rotary machine **23** and rotary machine controller **30**. Controller **30** is configured to send control signals to rotary machine **23** for causing rotary machine **23** to machine, grind or abrade component **24** with rotary tool **28**, which is mounted within spindle **26** of rotary machine **23**. For example, component **24** may be a covergalss, such as coverglass **150** (FIG. **3**). In different examples rotary tool **28**, may be one of rotary tools **100**, **200**, **300**, **400**, **500** or **600** as described later in this paper. In one example, rotary machine **23** may represent a CNC machine, such as a three, four or five axis CNC machine, capable of performing routing, turning, drilling, milling, grinding, abrading, and/or other machining operations, and controller **30** may include a CNC controller that issues instructions to spindle **26** for performing machining, grinding and/or abrading of component **24** with one or more rotary tools **28**. Controller **30** may include a general purpose computer running software, and such a computer may combine with a CNC controller to provide the functionality of controller **30**.

Component **24** is mounted to platform **38** in a manner that facilitates precise machining of component **24** by rotary machine **23**. Work holding fixture **18** secures component **24** to platform **38** and precisely locates component **24** relative to rotary machine **23**. Work holding fixture **18** may also provide a reference location for control programs of rotary machine **23**. While the techniques disclosed herein may apply to workpieces of any materials, component **24** may be a coverglass for an electronic device, such as a coverglass of a smartphone touchscreen.

In the example of FIG. **1**, rotary tool **28** is illustrated as including abrasive article **29**. In this example, abrasive article **29** may be utilized to improve the surface finish of machined features in component **24**, such as holes and edge features in a coverglass. In some example, different rotary tools **28** may be used in series to iteratively improve the surface finish of the machined features. For example, system **10** may be utilized to provide a coarser grinding step using a first rotary tool **28**, or set of rotary tools **28**, followed by a finer abrading step using a second rotary tool **28**, or set of rotary tools **28**. In the same or different examples, a single rotary tool **28** may include different levels of abrasion to facilitate an iterative grinding and/or abrading process using fewer rotary tools **28**. Each of these examples may reduce the cycle time for finishing and polishing a coverglass following the machining of the features in the coverglass as compared to other examples in which only a single grinding step is used to improve surface finish following machining of features in a coverglass.

In some examples, following grinding and/or abrading using system **10**, a coverglass may be polished, e.g., using a separate polishing system to further improve the surface finish. In general, the better the surface finish prior to polishing, the less time is required to provide a desired surface finish following the polishing.

To abrade an edge of component **24** with system **10**, controller **30** may issue instructions to spindle **26** to precisely apply abrasive article **29** against one or more features of component **24** as spindle **26** rotates rotary tool **28**. The instructions may include for example, instructions to precise follow the contours of features of component **24** with a single abrasive article **29** of a rotary tool **28** as well as iteratively apply multiple abrasive articles **29** of one or more rotary tools **28** to different features of component **24**.

In illustrative examples, as shown in FIG. **1**A, the abrasive article **29** may include a sub-base layer **41**, a base layer **43**, and an abrasive working surface **45**, with the base layer **43** interposed between the sub-base layer **41** and the abrasive working surface **45**. The abrasive working surface **45** may include a plurality of abrasive elements **47**.

In some embodiments, the sub-base layer **41** may include or be formed of a thermoplastic layer, e.g. a polycarbonate layer, which may impart greater stiffness to the pad, and may be used for global planarity. The sub-base layer **41** may also include elastically compressible material layers, e.g. foamed material layers. The sub-base layer **41** may further include combinations of thermoplastic and compressible material layers. Still further, sub-base layer **41** may include metallic films for static elimination or sensor signal monitoring, optically clear layers for light transmission, foam layers for finer finish of the workpiece to be polished, or ribbed materials for imparting a "hard band" or stiff region to the polishing surface. The layers of the sub-base layer **41**, as well as the sub-base layer **41** and base layer **43**, may be coupled to one another via any suitable fastening mechanism such as, for example, pressure sensitive adhesives, hot melt adhesives, or epoxies.

In some embodiments, the base layer **43** may be formed of a polymeric material. For example, the base layer of the abrasive article may be a conformable and flexible polymeric material capable of expanding and contracting in transverse directions. The conformability of the backing material is believed to result in the tools of the present disclosure being able to finish the coverglass workpiece to more complex or intricate final shape. Simple coverglass edge shapes would include bevel or quarter round shapes. For one quarter round example, a coverglass of thickness of 1.0 mm might require a single-sided radius of curvature of 1.0 mm. For another example, a coverglass of 0.7 mm thickness might require a single-sided radius of curvature of 0.7 mm. For yet another example, a coverglass of 0.5 mm thickness may require a single-sided radius of curvature of 0.5 mm. Commercial coverglass for portable electronic devices are typically in the range of 0.3 mm to 3.0 mm in thickness, in the range of 0.5 mm to 2.0 mm or in the range of 0.6 mm to 1.3 mm in thickness.

For example, the base layer may be formed from thermoplastics, for example; polypropylene, polyethylene, polycarbonate, polyurethane, polytetrafluoroethylene, polyethylene teraphthalate, polyethylene oxide, polysulphone, polyetherketone, polyetheretherketone, polyimides, polyphenylene sulfide, polystyrene, polyoxymethylene plastic and the like; thermosets, for example polyurethanes, epoxy resin, phenoxy resins, phenolic resins, melamine resins, polyimides and urea-formaldehyde resins, radiation cured resins, or combinations thereof. In some embodiments, the base layer may be formed from or include styrene and butadiene block copolymers. One suitable commercially available styrene and butadiene block copolymer material is known as KRATON D.

In some embodiments, the base layer **43** may be made of any number of various materials including those conventionally used as base layers in the manufacture of coated abrasives. Exemplary base layer **43** materials include polymeric films (including primed films) such as polyolefin film (e.g., polypropylene including biaxially oriented polypropylene, polyester film, polyamide film, cellulose ester film), metal foil, mesh, foam (e.g., natural sponge material or polyurethane foam), cloth (e.g., cloth made from fibers or yarns comprising polyester, nylon, silk, cotton, and/or rayon), scrim, paper, coated paper, vulcanized paper, vulcanized fiber, nonwoven materials, combinations thereof, and treated versions thereof. The base layer **43** may also be a laminate of two materials (e.g., paper/film, cloth/paper, film/cloth). Cloth base layers may be woven or stitch bonded. In some embodiments, the base layer **43** is a thin and conformable polymeric film capable of expanding and contracting in transverse (i.e. in-plane) directions during use. For example a strip of such a base layer material that is 5.1 centimeters (2 inches) wide, 30.5 centimeters (12 inches) long, and 0.102 millimeters (4 mils) thick and subjected to a 22.2 Newton (5 Pounds-Force) dead load longitudinally may stretch at least 0.1%, at least 0.5%, at least 1.0%, at least 1.5%, at least 2.0%. at least 2.5%, at least 3.0%, or at least 5.0%, relative to the original length of the strip. In some embodiments, a strip of the base layer **43** material may longitudinally stretch up to 20%, up to 18%, up to 16%, up to 14%, up to 13%, up to 12%, up to 11%, or up to 10%, relative to the original length of the strip. The stretching of the base layer material can be elastic (with complete spring back), inelastic (with zero spring back), or some mixture of both.

Highly conformable polymers that may be used in the base layer **43** include certain polyolefin copolymers, polyurethanes, and polyvinyl chloride. One particular polyolefin copolymer is an ethylene-acrylic acid resin (available under the trade designation "PRIMACOR 3440" from Dow Chemical Company, Midland, Mich.). Optionally, ethylene-acrylic acid resin is one layer of a bilayer film in which the other layer is a polyethylene terephthalate (PET) carrier film.

In some embodiments, the base layer **43** may include one or more polyurethanes. Suitable polyurethanes may include, or consist essentially of, at least one thermoplastic polyurethane (TPU). The term "consisting essentially of" as used in this context means that additive compounds (e.g., fragrances, colorants, antioxidants, UV light stabilizers, and/or fillers) may be present in the backing as long as tensile strength and ultimate elongation remains substantially unaffected by their presence. For example, the additives may have less than a 5 percent, less than 1 percent, effect on tensile strength and ultimate elongation. In some embodiments, the base layer **43** may include a single thermoplastic polyurethane or a combination of thermoplastic polyurethanes. One suitable class of polyurethanes is aromatic polyether-based polyurethanes, such as thermoplastic polyether-based polyurethanes. In some embodiments, the thermoplastic polyether-bases polyurethanes are derived from 4,4' methylenedicyclohexyl diisocyanate (MDI), a polyether polyol, and butanediol. Thermoplastic polyurethanes are well known and can be made according to many known techniques, or they may be obtained for commercial suppliers. For example, Lubrizol Corp., Cleveland, Ohio, is one commercial supplier of various thermoplastic polyurethanes such as, for example: polyester-based aromatic TPUs available under the trade designation "ESTANE GP TPU (B series)" (e.g., grades 52 DB, 55 DB, 60 DB, 72 DB, 80 AB, 85 AB, and 95 AB); and polyester and polyether based TPU s available under the trade designation "ESTANE 58000 TPU series" (e.g., grades 58070, 58091, 58123, 58130, 58133, 58134, 58137, 58142, 58144, 58201, 58202, 58206, 58211, 58212, 58213, 58215, 58219, 58226, 58237, 58238, 58244, 58245, 58246, 58248, 58252, 58271, 58277, 58280, 58284, 58300, 58309, 58311, 58315, 58325, 58370, 58437, 58610, 58630, 58810, 58863, 58881, and 58887).

In some embodiments, the base layer **43** may consist essentially of only one layer of material, or it may have a multilayered construction. For example, the base layer may include a plurality of layers, or layer stack, with the individual layers of the stack being coupled to one another with a suitable fastening mechanism (e.g, adhesive and/or primer layer). The base layer (or an individual layer of the layer stack) may have any shape and thickness. The base layer **43** may be impermeable to liquid water and substantially free of void space, although minor amounts of porosity may be acceptable. For example, the base layer **43** may have less than 10 percent, less than 2 percent, less than 1 percent, or even less than 0.01 percent of intrinsic voids (i.e., voids that are not deliberately added, but are an intrinsic property of the material making up the backing), based on the total volume of the base layer **43**. The base layer **43** may be cast (e.g., from solvent or water) or extruded. It may contain one or more additives such as fillers, melt processing aids, antioxidants, flame retardants, colorants, or ultraviolet light stabilizers or may also be coated with adhesion promotion agents such as Tie-Coat. The average thickness of the base layer (i.e., the dimension of the base layer in a direction normal to the first and second major surfaces) may be less than 10 mm, less than 5 mm, less than 1 mm, less than 0.5 mm, less than 0.25 mm, less than 0.125 mm, or less than 0.05 mm.

In some embodiments, the average thickness of the base layer **43** may range from about 0.02 to about 5 millimeters, from about 0.05 to about 2.5 millimeters, or from about 0.1 to about 0.4 millimeters, although thicknesses outside of these ranges may also be useful.

In some embodiments, the base layer **43** may have an average thickness of 1 to 10 mils, 1 to 6 mils, 4 to 6 mils (102 to 152 microns), 4.5 to 6.5 mils (114 to 165 microns), or 4.8 to 6.2 mils (122 to 157 microns). The base layer may, furthermore, have a number of physical properties that collectively impart flexibility and durability to the flexible abrasive articles.

In some embodiments, the base layer may have a tensile strength in the range of from 500 to 3200 psi (3.4 to 22.1 MPa), 1000 to 2500 psi (6.9 to 17.2 MPa), 1600 to 2100 psi (11.0 to 14.5 MPa), and an ultimate elongation (i.e., elongation at break) of 230 to 530 percent, 300 to 460 percent, or 350 to 410 percent.

In some embodiments, the abrasive article may have a tensile strength of from at least 400 psi (2.8 MPa), and an ultimate elongation of from at least 180 percent.

In some embodiments, the working surface **45** may include a two-dimensional abrasive material, such as a conventional abrasive sheet with a layer of abrasive particles held to a backing by one or more resin or other binder layers. Alternatively, the working surface **45** may be formed as a three-dimensional fixed abrasive, such as a resin or other binder layer that contains abrasive particles dispersed therein. In either example, the working surface **45** may include a plurality of abrasive elements **47** configured to wear during use and/or dressing to expose a fresh layer of abrasive material.

In some embodiments, as shown in FIG. **1**A, the working surface **45** may include a plurality abrasive elements **47** coupled to the base layer **43** via a suitable fastening mechanism, such as an adhesive or resin **49**. In some embodiments, the abrasive elements **47** may include porous ceramic abrasive composites. The porous ceramic abrasive composites may include individual abrasive particles dispersed in a porous ceramic matrix. As used herein the term "ceramic matrix" includes both glassy and crystalline ceramic materials. These materials generally fall within the same category when considering atomic structure. The bonding of the adjacent atoms is the result of process of electron transfer or electron sharing. Alternatively, weaker bonds as a result of attraction of positive and negative charge known as secondary bond can exist. Crystalline ceramics, glass and glass ceramics have ionic and covalent bonding. Ionic bonding is achieved as a result of electron transfer from one atom to another. Covalent bonding is the result of sharing valence electrons and is highly directional. By way of comparison, the primary bond in metals is known as a metallic bond and involves non-directional sharing of electrons. Crystalline ceramics can be subdivided into silica based silicates (such as fireclay, mullite, porcelain, and Portland cement), non-silicate oxides (e.g., alumna, magnesia, $MgAl_2O_4$, and zirconia) and non-oxide ceramics (e.g., carbides, nitrides and graphite). Glass ceramics are comparable in composition with crystalline ceramics. As a result of specific processing techniques, these materials do not have the long range order crystalline ceramics do. Glass ceramics are the result of controlled heat-treatment to produce at least about 30% crystalline phase and up to about 90% crystalline phase or phases.

In illustrative embodiments, at least a portion of the ceramic matrix includes glassy ceramic material. In some embodiments, the ceramic matrix includes at least 50% by weight, 70% by weight, 75% by weight, 80% by weight, or 90% by weight glassy ceramic material. In one embodiment, the ceramic matrix consists essentially of glassy ceramic material. Of particular usefulness for edge grinding coverglass, the ceramic matrix may include at least 30% by weight glassy ceramic material.

In various embodiments, the ceramic matrixes may include glasses that include metal oxides, for example, aluminum oxide, boron oxide, silicon oxide, magnesium oxide, sodium oxide, manganese oxide, zinc oxide, and mixtures thereof. A ceramic matrix may include alumina-borosilicate glass including Si_2O, B_2O_3, and Al_2O_3. The alumina-borosilicate glass may include about 18% B_2O_3, 8.5% Al_2O_3, 2.8% BaO, 1.1% CaO, 2.1% Na_2O, 1.0% Li_2O with the balance being Si_2O. Such an alumina-borosilicate glass is commercially available from Specialty Glass Incorporated, Oldsmar Fla.

As used herein the term "porous" is used to describe the structure of the ceramic matrix which is characterized by having pores or voids distributed throughout its mass. A porous ceramic matrix may be formed by techniques well known in the art, for example, by controlled firing of a ceramic matrix precursor or by the inclusion of pore forming agents, for example, glass bubbles, in the ceramic matrix precursor. The pores may be open to the external surface of the composite or sealed. Pores in the ceramic matrix are believed to aid in the controlled breakdown of the ceramic abrasive composites leading to a release of used (i.e., dull) abrasive particles from the composites. The pores may also increase the performance (e.g., cut rate and surface finish) of the abrasive article, by providing a path for the removal of swarf and used abrasive particles from the interface between the abrasive article and the workpiece. The voids (or pore volume) may comprise from about at least 4 volume % of the composite, at least 7 volume % of the composite, at least 10 volume % of the composite, or at least 20 volume % of the composite; less than 95 volume % of the composite, less than 90 volume % of the composite, less than 80 volume % of the composite, or less than 70 volume % of the composite. Of particular usefulness for edge grinding coverglass, the voids may comprise from between 35 percent to 65 percent by weight of the ceramic abrasive composites.

In some embodiments, the abrasive particles dispersed in the porous ceramic matrix may include diamond, cubic boron nitride, fused aluminum oxide, ceramic aluminum oxide, heated treated aluminum oxide, silicon carbide, boron carbide, alumina zirconia, iron oxide, ceria, garnet, and combinations thereof. In one example, the abrasive particles may include or consist essentially of diamond. Diamond abrasive particles may be natural or synthetically made diamond. The diamond particles may have a blocky shape with distinct facets associated with them or, alternatively, an irregular shape. The diamond particles may be mono-crystalline or polycrystalline such as diamond commercially available under the trade designation "Mypolex" from Mypodiamond Inc., Smithfield Pa. Monocrystalline diamond of various particles size may be obtained from Diamond Innovations, Worthington, Ohio. Polycrystalline diamond may be obtained from Tomei Corporation of America, Cedar Park, Tex. The diamond particles may contain a surface coating such as a metal coating (nickel, aluminum, copper or the like), an inorganic coating (for example, silica), or an organic coating. In some embodiments, the abrasive particles may include a blend of abrasive particles. For example, diamond abrasive particles may be mixed with a second, softer type of abrasive particles. In such instance, the second abrasive particles may have a smaller average particle size than the diamond abrasive particles.

In illustrative embodiments, the abrasive particles dispersed in the porous ceramic matrix may be uniformly (or substantially uniformly) distributed throughout the ceramic matrix. As used herein, "uniformly distributed" means that the unit average density of abrasive particles in a first portion of the composite particle does not vary by more than 20%, more than 15%, more than 10%, or more than 5% when compared with any second, different portion of the composite particle. This is in contrast to, for example, an abrasive composite particle having abrasive particles concentrated at the surface of the particle.

In various embodiments, the porous ceramic abrasive composites may also include optional additives such as fillers, coupling agents, surfactants, foam suppressors and the like. The amounts of these materials may be selected to provide desired properties. Additionally, the ceramic abrasive composites may include (or have adhered to an outer surface thereof) one or more parting agents. As will be discussed in further detail below, one or more parting agents may be used in the manufacture of the porous ceramic abrasive composites to prevent aggregation of the particles. Useful parting agents may include, for example, metal oxides (e.g, aluminum oxide), metal nitrides (e.g., silicon nitride), graphite, and combinations thereof.

In some examples, the porous ceramic abrasive composites useful in the articles and methods may have an average size (average major axial diameter or longest straight line between two points on a composite) of about at least 5 μm, at least 10 μm, at least 15 μm, or at least 20 μm; less than 1,000 μm, less than 500 μm, less than 200 μm, or less than 100 μm. Porous ceramic abrasive composites particularly useful for edge grinding coverglass may have an average particle size of less than about 65 μm and a max particle size of less than about 500 μm.

In illustrative examples, the average size of the porous ceramic abrasive composites is at least about 3 times the average size of the abrasive particles used in the composites, at least about 5 times the average size of the abrasive particles used in the composites, or at least about 10 times the average size of the abrasive particles used in the composites; less than 30 times the average size of the abrasive particles used in the composites, less than 20 times the average size of the abrasive particles used in the composites, or less than 10 times the average size of the abrasive particles used in the composites. Abrasive particles useful in the porous ceramic abrasive composites may have an average particle size (average major axial diameter (or longest straight line between two points on a particle)) of at least about 0.5 μm, at least about 1 μm, or at least about 3 μm; less than about 300 μm, less than about 100 μm, or less than about 50 μm. The abrasive particle size may be selected to, for example, provide a desired cut rate and/or desired surface roughness on a workpiece. The abrasive particles may have a Mohs hardness of at least 8, at least 9, or at least 10.

In various examples, the weight of abrasive particles to the weight of glassy ceramic material in the ceramic matrix of the porous ceramic abrasive composites is at least about 1/20, at least about 1/10, at least about 1/6, at least about 1/3, less than about 30/1, less than about 20/1, less than about 15/1 or less than about 10/1.

In various examples, a ratio of abrasive particle size to porous ceramic abrasive composites size may be no greater than 15 to 1, of no greater than 12.5 to 1, of no greater than 10 to 1. In some examples, a ratio of abrasive size to agglomerate size may also be no less than about 3 to 1, no less than about 5 to 1 or even no less than about 7 to 1. Ceramic abrasive composites providing such ratios of abrasive size to agglomerate size may be particularly useful for edge grinding coverglass.

In various examples, the amount of porous ceramic matrix in the ceramic abrasive composites is at least 5, at least 10, at least 15, at least 33, less than 95, less than 90, less than 80, or less than 70 weight percent of the total weight of the porous ceramic matrix and the individual abrasive particles, where the ceramic matrix includes any fillers, adhered parting agent and/or other additives other than the abrasive particles.

In various examples, the porous ceramic abrasive composites may be precisely-shaped or irregularly shaped (i.e., non-precisely-shaped). Precisely-shaped composites may be any shape (e.g., cubic, block-like, cylindrical, prismatic, pyramidal, truncated pyramidal, conical, truncated conical, spherical, hemispherical, cross, or post-like). The porous ceramic abrasive composites may be a mixture of different abrasive composite shapes and/or sizes. Alternatively, the porous ceramic abrasive composites may have the same (or substantially the same) shape and/or size. Non-precisely shaped composites may include spheroids, which may be formed from, for example, a spray drying process.

Generally, a method for making the porous ceramic abrasive composites includes mixing an organic binder, solvent, abrasive particles, e.g. diamond, and ceramic matrix precursor particles, e.g. glass frit; spray drying the mixture at elevated temperatures producing "green" abrasive/ceramic matrix/binder particles; the "green" abrasive/ceramic matrix/binder particles are collected and mixed with a parting agent, e.g. plated white alumina; the powder mixture is then annealed at a temperature sufficient to vitrify the ceramic matrix material that contains the abrasive particles while removing the binder through combustion; forming the ceramic abrasive composite. The porous ceramic abrasive composites can optionally be sieved to the desired particle size. The parting agent prevents the "green" abrasive/ceramic matrix/binder particles from aggregating together during the vitrifying process. This enables the vitrified, ceramic abrasive composites to maintain a similar size as that of the "green" abrasive/ceramic matrix/binder particles formed directly out of the spray drier. A small weight fraction, less than 10%, less 5% or even less than 1% of the parting agent may adhere to the outer surface of the ceramic matrix during the vitrifying process. The parting agent typically has a softening point (for glass materials and the like), or melting point (for crystalline materials and the like), or decomposition temperature, greater than the softening point of the ceramic matrix, wherein it is understood that not all materials have each of a melting point, a softening point, or a decomposition temperature. For a material that does have two or more of a melting point, a softening point, or a decomposition temperature, it is understood that the lower of the melting point, softening point, or decomposition temperature is greater than the softening point of the ceramic matrix. Examples of useful parting agents include, but are not limited to, metal oxides (e.g. aluminum oxide), metal nitrides (e.g. silicon nitride) and graphite.

The porous ceramic abrasive composites may be formed by any particle forming processes including, for example, casting, replication, microreplication, molding, spraying, spray-drying, atomizing, coating, plating, depositing, heating, curing, cooling, solidification, compressing, compacting, extrusion, sintering, braising, atomization, infiltration, impregnation, vacuumization, blasting, breaking (depending on the choice of the matrix material) or any other available method. The composites may be formed as a larger article and then broken into smaller pieces, as for example, by crushing or by breaking along score lines within the larger article. If the composites are formed initially as a larger body, it may be desirable to select for use fragments within a narrower size range by one of the methods known to those familiar with the art. In some examples, the porous ceramic abrasive composites may include vitreous bonded diamond agglomerates produced generally using techniques disclosed in of U.S. Pat. Nos. 6,551,366 and 6,319,108. Of particular usefulness for edge grinding coverglass, a volume ratio of diamond agglomerates to a resin binder within the abrasive is greater than 3 to 2.

In some examples, the porous ceramic abrasive composites may be surface modified (e.g., covalently, ionically, or mechanically) with reagents which will impart properties beneficial to abrasive slurries. For example, surfaces of glass can be etched with acids or bases to create appropriate surface pH. Covalently modified surfaces can be created by reacting the particles with a surface treatment comprising one or more surface treatment agents. Examples of suitable surface treatment agents include silanes, titanates, zirconates, organophosphates, and organosulfonates. Examples of silane surface treatment agents suitable for this invention include octyltriethoxysilane, vinyl silanes (e.g., vinyltrimethoxysilane and vinyl triethoxysilane), tetramethyl chloro silane, methyltrimethoxysilane, methyltriethoxysilane, propyltrimethoxysilane, propyltriethoxysilane, tris-[3-(trimethoxysilyl)propyl] isocyanurate, vinyl-tris-(2-methoxyethoxy)silane, gamma-methacryloxypropyltrimethoxysilane, beta-(3,4-epoxycyclohexyl)ethyltrimethoxysilane, gamma-glycidoxypropyltrimethoxysilane gamma-mercaptopropyltrimethoxysilane, gamma-aminopropyltriethoxysilane, gamma-aminopropyltrimethoxysilane, N-beta-(aminoethyl)-gamma-aminopropyltrimethoxysilane, bis-(gamma-trimethoxysilylpropyl)amine, N-phenyl-gamma-aminopropyltrimethoxysilane, gamma-ureidopropyltrialkoxysilane, gamma-ureidopropyltrimethoxysilane, acryloxyalkyl trimethoxysilane, methacryloxyalkyl trimethoxysilane, phenyl trichlorosilane, phenyltrimethoxysilane, phenyl triethoxysilane, SILQUEST A1230 proprietary non-ionic silane dispersing agent (available from Momentive, Columbus, Ohio) and mixtures thereof. Examples of commercially available surface treatment agents include SILQUEST A174 and SILQUEST A1230 (available from Momentive). The surface treatment agents may be used to adjust the hydrophobic or hydrophilic nature of the surface it is modifying. Vinyl silanes can be used to provide an even more sophisticated surface modification by reacting the vinyl group w/ another reagent. Reactive or inert metals can be combined with the glass diamond particles to chemically or physically change the surface. Sputtering, vacuum evaporation, chemical vapor deposition (CVD) or molten metal techniques can be used.

In some embodiments, the resin **49** may include an epoxy resin. Alternatively, or additionally, the resin **49** may include any resin suitable for fixing abraisved particles to a substrate. In addition to resin and porous ceramic abrasive composites, the working surface **45** may include additional additives, such as a filler material or other materials. In some examples, a filler material may include one or more of aluminum oxide, non-woven fibers, silicon carbide and ceria particles. In such examples, the filler material may represent between 5 percent to 50 percent by weight of the working surface **45**, based on the total weight of the porous ceramic abrasive composites and any filler materials. Such examples may be particularly useful for abrasive materials used for edge grinding coverglass.

As another example, the working surface **45** may include metal particles dispersed within the resin in combination with the porous ceramic abrasive composites. Metal particles may provide a bearing effect to protect the resin during a grinding operation. Such metal particles may include one or more of copper particles, tin particles, brass particles, aluminum particles, stainless steel particles and metal alloys. For example, the metal particles may represent between 5 percent to 25 percent by weight of the working surface **45**, based on the total weight of the porous ceramic abrasive composites and any metal particles. In the same or different examples, the metal particles may have an average particle size of between 10 micrometers to 250 micrometers, such as between 44 micrometers to 149 micrometers, such as about 100 micrometers. Such examples may be particularly useful for abrasive materials used for edge grinding coverglass.

In some embodiments, polymethyl methacrylate beads may be dispersed within the resin of the working surface **45**. In such examples, the polymethyl methacrylate beads may represent between 1 percent to 10 percent by weight of the working surface **45**, based on the total weight of the porous ceramic abrasive composites and the beads. Such examples may be particularly useful for abrasive materials used for edge grinding coverglass.

In some embodiments, the abrasive elements **47** may be arranged in an array to form a three-dimensional, textured, flexible, fixed abrasive construction. Such abrasive elements **47** may include abrasive particles dispersed in a matrix, such as those abrasive elements described in U.S. Pat. No. 5,958,794 (Bruxvoort et al.), which is hereby incorporated by reference in its entirety, which are oriented in monolithic rows and are precisely aligned and manufactured from a die, mold, emboss, or other techniques (hereinafter, referred to as precisely shape abrasive composites). Abrasive elements that are provided in the abrasive articles available under the trade designation TRIZACT patterned abrasive and TRIZACT diamond tile abrasives available from 3M Company, St. Paul, Minn., are exemplary precisely shaped abrasive composites.

In some embodiments, the matrix material of the precisely shaped abrasive composites may include a cured or curable organic material. The method of curing is not critical, and may include, for instance, curing via energy such as UV light or heat. Examples of suitable matrix materials include, for instance, amino resins, alkylated urea-formaldehyde resins, melamine-formaldehyde resins, and alkylated benzoguanamine-formaldehyde resins. Other matrix materials include, for instance, acrylate resins (including acrylates and methacrylates), phenolic resins, urethane resins, and epoxy resins. Particular acrylate resins include, for instance, vinyl acrylates, acrylated epoxies, acrylated urethanes, acrylated oils, and acrylated silicones. Particular phenolic resins include, for instance, resole and novolac resins, and phenolic/latex resins. In the same or different examples, the resin may include one or more of an epoxy resin, a polyester resin, a polyvinyl butyral (PVB) resin, an acrylic resin, thermal plastic resin, a thermally curable resin, an ultraviolet light curable resin, and an electromagnetic radiation curable resin. For example, an epoxy may represent between about 20 percent to about 35 percent by weight of the abrasive composite material. In the same or different examples, a polyester resin represents between 1 percent to 10 percent by weight of the abrasive composite material. The matrix may further contain conventional fillers and curing agents such as are described, for instance, in U.S. Pat. No. 5,958,794 (Bruxvoort et al.), incorporated herein by reference.

Examples of suitable abrasive particles for the precisely shaped abrasive composites include cubic boron nitride, fused aluminum oxide, ceramic aluminum oxide, heat treated aluminum oxide, white fused aluminum oxide, black silicon carbide, green silicon carbide, titanium diboride, boron carbide, silicon nitride, tungsten carbide, titanium carbide, diamond, cubic boron nitride, hexagonal boron nitride, alumina zirconia, iron oxide, ceria, garnet, fused alumina zirconia, alumina-based sol gel derived abrasive particles and the like. The alumina abrasive particle may contain a metal oxide modifier. Examples of alumina-based sol gel derived abrasive particles can be found in U.S. Pat. Nos. 4,314,827; 4,623,364; 4,744,802; 4,770,671; and 4,881,951, all incorporated by reference herein. The diamond and cubic boron nitride abrasive particles may be mono crystalline or polycrystalline. Other examples of suitable inorganic abrasive particles include silica, iron oxide, chromia, ceria, zirconia, titania, tin oxide, gamma alumina, and the like.

The shape of each precisely shaped abrasive composite may be selected for the particular application (e.g., workpiece material, working surface shape, contact surface shape, temperature, resin phase material). The shape of each precisely shaped abrasive composite may be any useful shape, e.g., cubic, cylindrical, prismatic, right parallelepiped, pyramidal, truncated pyramidal, conical, hemispherical, truncated conical, cross, or post-like sections with a distal end. Composite pyramids may, for instance, have three, four sides, five sides, or six sides. The cross-sectional shape of the abrasive composite at the base may differ from the cross-sectional shape at the distal end. The transition between these shapes may be smooth and continuous or may occur in discrete steps. The precisely shaped abrasive composites may also have a mixture of different shapes. The precisely shaped abrasive composites may be arranged in rows, spiral, helix, or lattice fashion, or may be randomly placed. The precisely shaped abrasive composites may be arranged in a design meant to guide fluid flow and/or facilitate swarf removal.

The lateral sides forming the precisely shaped abrasive composite may be tapered with diminishing width toward the distal end. The tapered angle may be from about 1 to less than 90 degrees, for instance, from about 1 to about 75 degrees, from about 3 to about 35 degrees, or from about 5 to about 15 degrees. The height of each precisely shaped abrasive composite may be the same, but it is possible to have precisely shaped abrasive composites of varying heights in a single article.

The base of the precisely shaped abrasive composites may abut one another or, alternatively, the bases of adjacent precisely shaped abrasive composites may be separated from one another by some specified distance. In some examples, the physical contact between adjacent abrasive composites involves no more than 33% of the vertical height dimension of each contacting precisely shaped abrasive composite. This definition of abutting also includes an arrangement where adjacent precisely shaped abrasive composites share a common land or bridge-like structure which contacts and extends between facing lateral surfaces of the precisely shaped abrasive composites. The abrasives are adjacent in the sense that no intervening composite is located on a direct imaginary line drawn between the centers of the precisely shaped abrasive composites.

The precisely shaped abrasive composites may be set out in a predetermined pattern or at a predetermined location within the working surface **45**. For example, when the abrasive article is made by providing an abrasive/resin slurry between a backing and mold, the predetermined pattern of the precisely shaped abrasive composites will correspond to the pattern of the mold. The pattern is thus reproducible from abrasive article to abrasive article.

The predetermined patterns may be in an array or arrangement, by which is meant that the composites are in a designed array such as aligned rows and columns, or alternating offset rows and columns. In another example, the abrasive composites may be set out in a "random" array or pattern. By this is meant that the composites are not in a regular array of rows and columns as described above. It is understood, however, that this "random" array is a predetermined pattern in that the location of the precisely shaped abrasive composites is predetermined and corresponds to the mold.

In various examples, abrasive articles **29** as described herein may be used to form an abrasive surface of an abrasive rotary tool particularly suitable for edge grinding coverglass. In some examples, the abrasive material, including resin, abrasive elements, and any additional additives dispersed in the resin, may be molded to form the abrasive surface or even an entire rotary tool **28**. For example, the abrasive material may be overmolded on a core of a rotary tool **28** to form the abrasive surface. In general, such a core would include the tool shank as well as a portion embedded in the abrasive material in order to mechanically secure the abrasive material to the tool shank.

In other examples, the abrasive articles **29** may be coupled to a substrate. The substrates may represent a core of a rotary tool **28** providing the shape of the rotary tool, with the abrasive articles **29** applied directly to the core of the rotary tool. In other examples, the substrate may represent a sheet material later applied to a core of a rotary tool. In such examples, the substrate may be a flat substrate or a curved substrate. In various examples, the substrate may include one or more of a polymer film, a non-woven substrate, a woven substrate, a rubber substrate, an elastic substrate, a foam substrate, a conformable material, an extruded film, a primed substrate, and an unprimed substrate.

FIGS. **2** and **4A-9** illustrate example rotary abrasive tools suitable for grinding of a glass, such as a coverglass, sapphire, ceramics, and the like, whereas FIG. **3** illustrates a coverglass for an electronic device. Each of the tools of FIGS. **2** and **4A-9** may include an abrasive article **29** and/or working surface **45** as described herein, and may be utilized as rotary tool **28** within system **10** (FIG. **1**).

In particular, FIG. **2** illustrates an example rotary abrasive tool **100**. Rotary abrasive tool **100** includes a set of flexible flaps **104** with abrasive external surface **106**, **108** that facilitate abrading an edge of a workpiece across multiple angles through bending of the flexible flaps. For example, the abrasive external surfaces **106**, **108** may include or be formed of an abrasive article **29** and/or working surface **45** as described herein. Rotary abrasive tool **100** further includes tool shank **102**, which defines an axis of rotation for tool **100**. Flexible flaps **104** may secured to tool shank **102** with an optional fixation mechanism **105**, which may represent a pin, screw, rivet or other fixation mechanism. Tool shank **102** may be configured to mount within a chuck of a rotary machine, such as a drill or CNC machine.

Flexible flaps **104** form a flexible planar section positioned opposite tool shank **102**. Each of flexible flaps **104** form a first abrasive external surface **106** on a first side of the flexible flaps **104**, the first side of flexible flaps **104** facing generally away from tool shank **102**. Each of flexible flaps **104** also form an optional second abrasive external surface **108** on a second side of flexible flaps **104**, the second side of flexible flaps **104** facing in the general direction of tool shank **102**. Optional substrate **110** is located between first abrasive external surface **106** and second abrasive external surface **108**. In some examples, substrate **110** may include an elastically compressible layer backing abrasive external surfaces **106**, **108**.

Rotary abrasive tool **100** further includes cylindrical section **114** attached to tool shank **102**. Cylindrical section **114** forms third abrasive external surface **116** surrounding the axis of rotation **103**. Cylindrical section **114** may further include an optional elastically compressible layer backing abrasive external surface **116**. Flexible flaps **104** extend past the outer diameter of cylindrical section **114** relative to axis of rotation **103**.

One or more of abrasive external surfaces **106**, **108** and **116** may be formed of or include an abrasive article **29** and/or working surface **45** as previously described herein. In the same or different examples, one or more of abrasive external surfaces **106**, **108** and **116**. Such article or surfaces may be secured to a substrate of tool **100**, such as substrate **110**, with an epoxy.

In different examples, as described herein, the abrasive of one or more of abrasive external surfaces **106**, **108** and **116** may provide an abrasive grain size of less than 20 micrometers, such as an abrasive grain size of between about 10 micrometers and about 1 micrometer, such as an abrasive grain size of about 3 micrometers. Such examples may be particularly useful for edge grinding of a coverglass.

In some examples, third abrasive external surface **116** of cylindrical section **114** may include portions with different abrasive grain sizes from one another. In such examples, the different portions may be utilized in series to provide improved surface finish or speed for surface finishing during a grinding operation, such as edge grinding of a coverglass.

As described in further detail with respect to FIGS. **4**A-**4**C, cylindrical section **114** facilitates abrading an edge of the workpiece between the first side of the workpiece and the second side of the workpiece while operating of tool **100** from tool shank **102**. In addition, flexible flaps **104** facilitate abrading, with first abrasive external surface **106**, a first corner adjacent to a first side of a workpiece across multiple angles relative to the axis of rotation for the rotary tool through bending of flexible flaps **104** when first abrasive external surface **106** is applied to the first corner of the workpiece. Similarly, flexible flaps **104** facilitates abrading, with second abrasive external surface **108**, a second corner adjacent to a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece, across multiple angles relative to the axis of rotation for the rotary tool through bending of flexible flaps **104** when second abrasive external surface **108** is applied to the second corner of the workpiece.

FIG. **3** illustrates coverglass **150**, which is a coverglass for an electronic device, a cellular phone, personal music player or other electronic device. In some examples, coverglass **150** may be a component of a touchscreen for the electronic device. Coverglass **150** may be an alumina-silicate based glass with a thickness of less than 1 millimeter, although other compositions are also possible.

Coverglass **150** includes a first major surface **162** opposing a second major surface **164**. Generally, but not always, major surfaces **162**, **164** are planar surfaces. Edge surface **166** follows the perimeter of major surfaces **162**, **164**, the perimeter including rounded corners **167**. Coverglass **150** further forms a hole **152**. Hole **152** includes its own edge surfaces, such as edge surface **153** (see FIG. **4**A).

To provide an increased resistance to cracking and improved appearance, the surfaces of coverglass **150**, including major surfaces **162**, **164**, edge surface **166** and the edge surfaces of hole **152**, should be smoothed to the extent practical during manufacturing of coverglass **150**. After machining to form the general shape of coverglass **150**, the surfaces may be polished, e.g., using a CeO slurry, to remove grinding and machining marks in coverglass **150**.

In addition, as disclosed herein, rotary abrasive tools, such as those described with respect to FIGS. **2** and **4**A-**9** may be used to reduce edge surface roughness, such as edge surface **166** and the edge surfaces of hole **152**, using a CNC machine prior to polishing. The intermediate grinding step may reducing polishing time to provide desired surface finish qualities of coverglass **150** may not only reduce production time, but may also provide more precise dimensional control for the production of coverglass **150**.

FIGS. **4**A-**4**C illustrate rotary abrasive tool **100** being used to abrade coverglass **150**, which may represent a partially-finished coverglass in that it has not yet be polished or hardened following machining to form its general shape. Rotary abrasive tool **100** may first be secured to a rotary tool holder of a CNC machine, such as rotary machine **23**.

As illustrated in FIG. **4**A, surface **106** of the flexible section of tool **100**, flexible flaps **104**, are being used to abrade the corners between edge **153** of hole **152** and major surface **162**. The flexibility of flexible flaps **104** allows surface **106** to conform to the contours of the corners between edge **153** of hole **152** and major surface **162** as rotary abrasive tool **100** is pushed through hole **152**, e.g., by a CNC machine according to a preprogrammed set of instructions. In different examples, these corners may be rounded, beveled or square prior to the abrading by tool **100**. Likewise, the flexibility of flexible flaps **104** allows surface **106** to conform to the contours of other corners, including the corners of between edge **166** and major surface **162** to facilitate abrading these corners with surface **106**. In different examples, the corners of between edge **166** and major surface **162** may be rounded, beveled or square prior to the abrading by tool **100**. Similarly, any of tools **200**, **400**, **500** and **600**, which are described below with respect to FIGS. **5** and **7**-**9**, may also be used to abrade the corners of between edge **166** and major surface **162**.

Flexible flaps **104** are also flexible enough to push entirely through hole **152**, in order to allow abrasive external surface **116** of cylindrical section **114** to abrade edge **153** of hole **152**, as shown in FIG. **4**B. In addition, the flexibility of flexible flaps **104** allows surface **108** to conform to the contours of the corners between edge **153** of hole **152** and major surface **164** as rotary abrasive tool **100** is pulled back through hole **152**, e.g., by the CNC machine. In different examples, these corners may be rounded, beveled or square prior to the abrading by tool **100**. Likewise, the flexibility of flexible flaps **104** allows surface **106** to conform to the contours of other corners, including the corners of between edge **166** and major surface **164** to facilitate abrading these corners with surface **108**. Similarly, any of tools **200**, **400** and **500**, which are described below with respect to FIGS. **5**, **7** and **8**, may also be used to abrade the corners of between edge **166** and major surface **162** at hole **152**.

In this manner, tool **100** allows abrading all the surfaces associated with hole **152**, including edge **153** and the corners between edge **153** and major surfaces **162**, **164**. Such abrading may occur by continuously rotating tool **100** while contacting the surfaces associated with hole **152** with abrasive surfaces **106**, **116** and **108**. Tool **100** also allows abrading all the surfaces associated with edge **166** including the corners between edge **166** and major surfaces **162**, **164**. Such abrading may occur by continuously rotating tool **100** while contacting the surfaces associated with edge **166** with abrasive surfaces **106**, **116** and **108**. Following the abrading of surfaces associated edges **153**, **166** using tool **100**, these surfaces may be polished using an abrasive slurry, such as a CeO slurry, to further improve the surface finish. In the same or different examples in which an abrasive slurry is used, tool **100** may be part of a set of two or more tools **100** that provide different levels of abrasion. For example, the tools may be used in series from a rougher levels of abrasiveness to lower levels of abrasiveness to refine the surface finish.

FIG. **5** illustrates rotary abrasive tool **200**. Rotary abrasive tool **200** is substantially similar to rotary abrasive tool **100**, except that rotary abrasive tool **200** includes two sets of flexible flaps **204**, **234** with abrasive external surfaces, rather than a single set of flexible flaps **104**. Flexible flaps **204**, **234** may include different levels of abrasion

Rotary abrasive tool **200** includes two set of flexible flaps **204**, **234** with abrasive external surfaces **206**, **208**, **236**, **238** that facilitates abrading an edge of a workpiece across multiple angles through bending of the flexible flaps. Rotary abrasive tool **200** further includes tool shank **202**, which defines an axis of rotation for tool **200**. Flexible flaps **204** may secured to tool shank **202** with an optional fixation mechanism **205**, which may represent a pin, screw, rivet or other fixation mechanism. Tool shank **202** may be configured to mount within a chuck of a rotary machine, such as a drill or CNC machine.

Flexible flaps **204** form a flexible planar section positioned opposite tool shank **202** relative to cylindrical section **214**. Flexible flaps **204** extend past the outer diameter of cylindrical section **214** relative to the axis of rotation. Each of flexible flaps **204** form a first abrasive external surface **206** on a first side of the flexible flaps **204**, the first side of flexible flaps **204** facing generally away from tool shank **202**. Each of flexible flaps **204** also form an optional second abrasive external surface **208** on a second side of flexible flaps **204**, the second side of flexible flaps **204** facing in the general direction of tool shank **202**.

Rotary abrasive tool **200** further includes cylindrical section **214** attached to tool shank **202**. Cylindrical section **214** forms third abrasive external surface **216** surrounding the axis of rotation for rotary abrasive tool **200**. Abrasive external surface **216** includes two portions **227**, **228** with different abrasive grain sizes. The different portions may be utilized in series to provide improved surface finish or speed for surface finishing during a grinding operation, such as edge grinding of a coverglass. In other examples, more than two abrasive grain sizes may be included. [0089] Flexible flaps **234** form a flexible planar section positioned adjacent tool shank **202**. Flexible flaps **234** extend past the outer diameter of cylindrical section **214** relative to the axis of rotation. Each of flexible flaps **234** form a first abrasive external surface **236** on a first side of the flexible flaps **234**, the first side of flexible flaps **234** facing generally away from tool shank **202**. Each of the flexible flaps **234** also form an optional second abrasive external surface **238** on a second side of flexible flaps **234**, the second side of flexible flaps **234** facing in the general direction of tool shank **202**.

One or more of abrasive external surfaces **206**, **208**, **216**, **236** and **238** may include or be formed of an abrasive article **29** and/or working surface **45** as previously described herein. Such articles or surfaces may be secured to a substrate of tool **200** with an epoxy, adhesive or other material.

As described previously with respect to rotary tool **100**, cylindrical section **214** facilitates abrading an edge of the workpiece between the first side of the workpiece and the second side of the workpiece while operating of tool **200** from tool shank **202**. In addition, flexible flaps **204**, **234** facilitate abrading, with one of first abrasive external surfaces **206**, **236** a first corner adjacent to a first side of a workpiece across multiple angles relative to the axis of rotation for the rotary tool through bending of flexible flaps **204**, **234** when the one of first abrasive external surfaces **206**, **236** is applied to the first corner of the workpiece. Similarly, flexible flaps **204**, **234** facilitate abrading, with one of second abrasive external surfaces **208**, **238**, a second corner adjacent to a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece, across multiple angles relative to the axis of rotation for the rotary tool through bending of flexible flaps **204**, **234** when the one second one of abrasive external surface **208**, **238** is applied to the second corner of the workpiece.

In some examples, abrasive external surface **206** may provide a larger abrasive grain size than abrasive external surface **236**. And abrasive external surface **238** may provide a larger abrasive grain size than abrasive external surface **208**. In this manner, as tool **200** is pushed entirely through a hole, a first edge is abraded by external surface **206**, then external surface **236**, whereas the opposing edge is first abraded by external surface **238**, then external surface **208** as as tool **200** is pulled from the hole.

Following the abrading of surfaces of a workpiece using tool **200**, these surfaces may be polished using an abrasive slurry, such as a CeO slurry, to further improve the surface finish. In the same or different examples in which an abrasive slurry is used, tool **200** may be part of a set of two or more tools **200** that provide different levels of abrasion. For example, the tools may be used in series from a rougher levels of abrasiveness to lower levels of abrasiveness to refine the surface finish of a workpiece, such as coverglass **150**.

FIG. **6** illustrates rotary abrasive tool **300**. Rotary abrasive tool **300** is substantially similar to rotary abrasive tool **100**, except that rotary abrasive tool **300** does not include flexible flaps **104**.

Rotary abrasive tool **300** includes tool shank **302**, which defines an axis of rotation for tool **300**. Tool shank **302** may be configured to mount within a chuck of a rotary machine, such as a drill or CNC machine. Rotary abrasive tool **300** further includes cylindrical section **314** in coaxial alignment with, and attached to, tool shank **302**. Cylindrical section **314** forms an abrasive external surface **316** with circular cross sections perpendicular to the axis of rotation of tool **300**. In some examples, two or more abrasive grain sizes may be included in different portions of abrasive external surface **316**. Abrasive external surface **316** may include an abrasive coating as previously described herein. In the same or different examples, abrasive external surface **316** may include an abrasive film as also previously described herein.

Following the abrading of surfaces of a workpiece using tool **300**, these surfaces may be polished using an abrasive slurry, such as a CeO slurry, to further improve the surface finish. In in the same or different examples in which an abrasive slurry is used, tool **300** may be part of a set of two or more tools **300** that provide different levels of abrasion. For example, the tools may be used in series from a rougher levels of abrasiveness to lower levels of abrasiveness to refine the surface finish.

FIG. **7** illustrates rotary abrasive tool **400**. Rotary abrasive tool **400** is substantially similar to rotary abrasive tool **300**, with the addition of an angled surface including an abrasive external surface **440** for abrading a beveled edge of a workpiece, such as coverglass **150**.

Rotary abrasive tool **400** includes tool shank **402**, which defines an axis of rotation for tool **400**. Tool shank **402** may be configured to mount within a chuck of a rotary machine, such as a drill or CNC machine. Rotary abrasive tool **400** further includes cylindrical section **414** in coaxial alignment with, and attached to, tool shank **402**. Cylindrical section **414** forms an abrasive external surface **416** with circular cross sections perpendicular to the axis of rotation of tool **400**. In some examples, two or more abrasive grain sizes may be included in different portions of abrasive external surface **416**.

Rotary abrasive tool **400** further includes second abrasive external surface **440**, which forms an angled surface relative to the axis of rotation for abrasive tool **400**. Abrasive external surface **440** may facilitate abrading interior or exterior beveled edges of the workpiece, such as workpiece **150**. The shape of abrasive external surface **440** thereby corresponds to a desired finished shape of an edge of the workpiece. In other examples, a rotary tool may include different geometry to correspond to a desired finished shape of an edge of the workpiece.

Abrasive external surfaces **416**, **440** may include or be formed of an abrasive article **29** and/or working surface **45** as previously discussed.

Following the abrading of surfaces of a workpiece using tool **400**, these surfaces may be polished using an abrasive slurry, such as a CeO slurry, to further improve the surface finish. In in the same or different examples in which an abrasive slurry is used, tool **400** may be part of a set of two or more tools **400** that provide different levels of abrasion. For example, the tools may be used in series from a rougher levels of abrasiveness to lower levels of abrasiveness to refine the surface finish.

FIG. **8** illustrates rotary abrasive tool **500**. Rotary abrasive tool **500** is substantially similar to rotary abrasive tool **300**, with the addition of an angled surfaces including an abrasive external surfaces **542**, **544** for abrading beveled edges of a workpiece, such as coverglass **150**.

Rotary abrasive tool **500** includes tool shank **502**, which defines an axis of rotation for tool **500**. Tool shank **502** may be configured to mount within a chuck of a rotary machine, such as a drill or CNC machine. Rotary abrasive tool **500** further includes cylindrical section **514** in coaxial alignment with, and attached to, tool shank **502**. Cylindrical section **514** forms an abrasive external surface **516** with circular cross sections perpendicular to the axis of rotation of tool **500**. In some examples, two or more abrasive grain sizes may be included in different portions of abrasive external surface **516**.

Rotary abrasive tool **500** further includes abrasive external surfaces **542**, **544** on either side of cylindrical section **514**. Abrasive external surfaces **542**, **544** form angled surfaces relative to the axis of rotation for abrasive tool **500**. Abrasive external surface **542** may secured to tool shank **202** with an optional fixation mechanism **205**, which may represent a pin, screw, rivet or other fixation mechanism. Abrasive external surfaces **542**, **544** may facilitate abrading interior or exterior beveled edges of the workpiece, such as workpiece **150**. For example, external surface **542** may be configured to facilitate abrading interior or exterior beveled edges on a first side of the workpiece, whereas external surface **542** may be configured to facilitate abrading interior or exterior beveled edges on a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece. The shape of abrasive external surfaces **542**, **544** thereby corresponds to a desired finished shapes of the workpiece. In other examples, a rotary tool may include different geometry to correspond to a desired finished shape of an edge of the workpiece.

Abrasive external surfaces **516**, **542**, **544** may include or be formed of an abrasive article **29** and/or working surface **45** as previously described herein.

Following the abrading of surfaces of a workpiece using tool **500**, these surfaces may be polished using an abrasive slurry, such as a CeO slurry, to further improve the surface finish. In in the same or different examples in which an abrasive slurry is used, tool **500** may be part of a set of two or more tools **500** that provide different levels of abrasion. For example, the tools may be used in series from a rougher levels of abrasiveness to lower levels of abrasiveness to refine the surface finish.

FIG. **9** illustrates an example rotary abrasive tool including an abrasive external surface forming a planar surface perpendicular with the axis of rotation for the rotary tool.

FIG. **6** illustrates rotary abrasive tool **600**. Rotary abrasive tool **600** includes tool shank **602**, which defines an axis of rotation for tool **600**. Tool shank **602** may be configured to mount within a chuck of a rotary machine, such as a drill or CNC machine. Planar tool core **606** is mounted to tool shank **602** and perpendicular to the axis of rotation for tool **600**. In some examples, planar tool core **606** and tool shank **602** may represent a unitary component.

Rotary abrasive tool **600** includes planar abrasive external surface **650**, which is perpendicular to the axis of rotation for tool **600**. Relief notches **552** are located within the surface of planar abrasive external surface **650** to facilitate debris removal during a grinding operation with tool **600**. Rotary abrasive tool **600** also includes angled abrasive surface **654**, which facilitates abrading interior or exterior beveled edges of a workpiece, such as coverglass **150**. Planar abrasive external surface **650** and abrasive surface **654** provide circular cross sections perpendicular to the axis of rotation of tool **600**.

Abrasive external surfaces **650**, **654** may include an abrasive coating as previously described herein. In the same or different examples, abrasive external surfaces **650**, **654** may include an abrasive film as also previously described herein.

Following the abrading of surfaces of a workpiece using tool **600**, these surfaces may be polished using an abrasive slurry, such as a CeO slurry, to further improve the surface finish. In in the same or different examples in which an abrasive slurry is used, tool **600** may be part of a set of two or more tools **600** that provide different levels of abrasion. For example, the tools may be used in series from a rougher levels of abrasiveness to lower levels of abrasiveness to refine the surface finish.

FIG. **10** is a flowchart illustrating example techniques for manufacturing a rotary tool with an epoxy abrasive sheet. First, an abrasive sheet including a partially-cured epoxy is cut to fit an abrasive surface of a rotary tool (**702**). Then the cut sheet is wrapped and adhered to a core of the rotary tool (**704**). Once the abrasive is in place on the core of the rotary tool, the epoxy of the abrasive material is further cured to increase the hardness and durability of the abrasive material (**706**).

In some particular examples, the abrasive material may include a plurality of ceramic abrasive agglomerates dispersed in an epoxy resin as previously described. In the same or different examples, the sheet of abrasive material may include the abrasive material deposited on a polymeric film with a primer layer between the abrasive composite layer and the polymeric film. The polymeric film itself may be positioned over a compliant layer, such as a foam, with an adhesive securing the polymeric film to the complaint layer. The combined abrasive material coating, polymeric material and complaint material may then be applied to the core of rotary tool in order to form the shape of abrasive surface on rotary tool in accordance with the techniques of FIG. **10**.

Listing of Embodiments

1. An abrasive rotary tool comprising:

a tool shank defining an axis of rotation for the rotary tool; and

an abrasive external working surface coupled to the tool shank, wherein the abrasive external working surface comprises:

a resin; and

a plurality of porous ceramic abrasive composites dispersed in the resin, the porous ceramic abrasive composites comprising individual abrasive particles dispersed in a porous ceramic matrix, material, wherein at least a portion of the porous ceramic matrix comprises glassy ceramic wherein a ratio of the average porous ceramic abrasive composite size to the average individual abrasive particle size is no greater than 15 to 1.

2. The abrasive rotary tool of embodiment 1, wherein the resin includes an epoxy resin.

3. The abrasive rotary tool of embodiment 1, wherein the resin includes one or more of a group consisting of:

a polyester resin;

a polyvinyl butyral (PVB) resin;

an acrylic resin;

thermal plastic resin;

a thermally curable resin;

an ultraviolet light curable resin; and electromagnetic radiation curable resin.

4. The abrasive rotary tool of embodiment 1, wherein the epoxy resin represents between about 20 percent to about 35 percent by weight of the working surface, based on the total weight of the resin and the porous ceramic abrasive composites.

5. The abrasive rotary tool of embodiment 3 or embodiment 4, wherein the resin comprises a polyester resin, and the polyester resin represents between 1 percent to 10 percent by weight of the working surface, based on the total weight of the resin and the porous ceramic abrasive composites.

6. The abrasive rotary tool of any of the preceding embodiments, wherein the individual abrasive particles comprise diamond.

7. The abrasive rotary tool of any of the preceding embodiments, wherein the individual abrasive particles include one or more from a group consisting of:

cubic boron nitride; fused aluminum oxide; ceramic aluminum oxide;

heated treated aluminum oxide; silicon carbide; boron carbide; alumina zirconia; iron oxide; ceria; and garnet.

8. The abrasive rotary tool of any one of the preceding embodiments, wherein the porous ceramic abrasive composites have an average particle size of less than 65 microns and a max particle size of less than 500 microns.

9. The abrasive rotary tool of any of the preceding embodiments, wherein the average size of the porous ceramic abrasive composites is at least about 5 times the average size of the abrasive particles.

10. The abrasive rotary tool of any of the preceding embodiments, wherein the porous ceramic abrasive composites represent between 35 percent to 65 percent by weight of the working surface, based on the total weight of the resin and the porous ceramic abrasive composites.

11. The abrasive rotary tool of any of the preceding embodiments, wherein a volume ratio of porous ceramic abrasive composites to the resin is greater than 3 to 2.

12. The abrasive rotary tool of any of the preceding embodiments, wherein the porous ceramic abrasive composites have a pore volume ranging from 4 percent to 70 percent.

13. The abrasive rotary tool of any of the preceding embodiments, wherein the porous ceramic matrix comprises a glass including one or more from a group consisting of: aluminum oxide; boron oxide; silicon oxide; magnesium oxide; sodium oxide; manganese oxide; and zinc oxide.

14. The abrasive rotary tool of any of the preceding embodiments, wherein the porous ceramic matrix comprises at least 30 percent by weight glassy ceramic material, based on the total weight of the matrix.

15. The abrasive rotary tool of any of the preceding embodiments, wherein the porous ceramic matrix consists essentially of glassy ceramic material.

16. The abrasive rotary tool of any of the preceding embodiments, further comprising metal particles dispersed in the resin.

17. The abrasive rotary tool of embodiment 16, wherein the metal particles include one or more from a group consisting of: copper particles; tin particles; brass particles; aluminum particles; stainless steel particles; metal alloys; and a blend of more than one metal particle composition.

18. The abrasive rotary tool of embodiment 16 or embodiment 17, wherein the metal particles represent between 5 percent to 20 percent by weight of the working surface, based on the total weight of the abrasive external working surface.

19. The abrasive rotary tool of any of embodiments 16-18, wherein the metal particles have an average particle size of between 10 micrometers to 250 micrometers.

20. The abrasive rotary tool of any of embodiments 16-19, wherein the metal particles have an average particle size of between 44 micrometers to 149 micrometers.

21. The abrasive rotary tool of any of embodiments 16-20, wherein the metal particles have an average particle size of about 100 micrometers.

22. The abrasive rotary tool of any of the preceding embodiments, further comprising polymethyl methacrylate beads.

23. The abrasive rotary tool of embodiment 22, wherein the polymethyl methacrylate beads represent between 1 percent to 10 percent by weight of the working surface, based on the total weight of the abrasive external working surface.

24. The abrasive rotary tool of any of the preceding embodiments, further comprising a filler material.

25. The abrasive rotary tool of embodiment 24, wherein the filler material includes one or more of a group consisting of: aluminum oxide non-woven fibers; silicon carbide; and ceria particles.

26. The abrasive rotary tool of embodiment 24 or embodiment 25, wherein the filler material represents between 5 percent to 50 percent by weight of the working surface, based on the total weight of the abrasive external working surface.

27. The abrasive rotary tool of any of the preceding embodiments, wherein the abrasive external working surface is a molded surface.

28. The abrasive rotary tool of any of the preceding embodiments, wherein the abrasive external working surface forms an arrangement of precisely shaped abrasive

agglomerates, each precisely shaped abrasive agglomerate being tapered with diminishing width toward its distal end.

29. The abrasive rotary tool of any of embodiments 1-26, wherein the abrasive external working surface is a coating disposed on a substrate.

30. The abrasive rotary tool of embodiment 29, wherein the substrate is a flat substrate.

31. The abrasive rotary tool of embodiment 29, wherein the substrate is a curved substrate.

32. The abrasive rotary tool of any of embodiments 29-31, wherein the substrate includes one or more of a group consisting of:

a polymer film;

a non-woven substrate;

a woven substrate; a rubber substrate; an elastic substrate; a foam substrate;

a conformable material;

an extruded film;

a primed substrate; and an unprimed substrate.

33. The abrasive rotary tool of any of embodiments 29-32, wherein the substrate is a sheet material.

34. The abrasive rotary tool of any of embodiments 29-32, wherein the substrate is a core of a rotary abrasive tool, and the working surface is applied directly to the core of the rotary abrasive tool.

35. The abrasive rotary tool of any of the preceding embodiments, wherein a ratio of the average porous ceramic abrasive composites size to the average individual abrasive particle size is no greater than 10 to 1.

36. The abrasive rotary tool of any of the preceding embodiments, further comprising a flexible planar section positioned opposite the tool shank relative to the cylindrical section, wherein the flexible planar section forms the abrasive external working surface on a first side of the flexible planar section facing generally away from the tool shank, wherein the flexible planar section facilitates abrading, with the abrasive external working surface, a corner of the workpiece across multiple angles relative to the axis of rotation for the rotary tool through bending of the flexible planar section when the abrasive external working surface is applied to the corner of the workpiece.

37. The abrasive rotary tool of embodiment 36,

wherein the abrasive external working surface is a first abrasive external working surface, the abrasive rotary tool further comprising a second abrasive external working surface on a second side of the flexible planar section, the second side of the flexible planar section facing in the general direction of the tool shank,

wherein the corner is a first corner of the workpiece adjacent a first side of the workpiece, and wherein the flexible planar section facilitates abrading, with the second abrasive external working surface, a second corner adjacent to a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece, across multiple angles relative to the axis of rotation for the rotary tool through bending of the flexible planar section when the second abrasive working external surface is applied to the second corner of the workpiece.

38. The abrasive rotary tool of embodiment 37, wherein the first corner of the workpiece and the second corner of the workpiece are formed by a hole in the workpiece extending from the first side to the second side.

39. The abrasive rotary tool of any of embodiments 1-35, wherein the abrasive external working surface includes an abrasive cylindrical surface.

40. The abrasive rotary tool of any of embodiments 1-35, wherein the abrasive external working surface surrounds the axis of rotation for the rotary tool, the abrasive external working surface providing one or more circular cross sections perpendicular to the axis of rotation such that tool shape corresponds to a desired finished shape of an edge of the workpiece.

41. The abrasive rotary tool of any of embodiments 1-35, wherein the abrasive external working surface forms a cylindrical shape in coaxial alignment with the axis of rotation for the rotary tool.

42. The abrasive rotary tool of embodiment 41, wherein the abrasive external working surface is a first abrasive external working surface, the abrasive rotary tool further comprising a second abrasive external working surface forming an angled surface relative to the axis of rotation for the rotary tool to facilitate abrading interior or exterior beveled edges of the workpiece.

43. The abrasive rotary tool of embodiment 42, wherein the angled surface is a first angled surface, the abrasive rotary tool further comprising a third abrasive external working surface forming a second angled surface relative to the axis of rotation for the rotary tool to facilitate abrading interior or exterior beveled edges of the workpiece, wherein first angled surface is configured to facilitate abrading interior or exterior beveled edges on a first side of the workpiece, and wherein second angled surface is configured to facilitate abrading interior or exterior beveled edges on a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece.

44. The abrasive rotary tool of embodiment 43, wherein the cylindrical shape is between the first angled surface and the second angled surface along the axis of rotation for the rotary tool.

45. The abrasive rotary tool of any of embodiments 1-35, wherein the abrasive external surface forms a planar surface perpendicular with the axis of rotation for the rotary tool.

46. The abrasive rotary tool of any of embodiments 1-35, wherein the abrasive external working surface forms an angled surface relative to the axis of rotation for the rotary tool to facilitate abrading interior or exterior beveled edges of the workpiece.

47. The abrasive rotary tool of any of the proceeding embodiments, further comprising an elastically compressible layer backing the abrasive external working surface.

48. A method of finishing an edge of a partially-finished cover glass for an electronic device, the method comprising:

continuously the rotating abrasive rotary tool of any of the proceeding embodiments;

contacting the edge with the abrasive external surface of the continuously rotating abrasive rotary tool to abrade the edge.

49. The method of embodiment 48, further comprising, after abrading the edge with the abrasive rotary tool, polishing the edge using an abrasive slurry.

50. The abrasive rotary tool of any of the preceding embodiments, further comprising an abrasive article, the abrasive article comprising the abrasive external working surface and a base layer coupled to the abrasive external working surface, wherein the base layer comprises a polyurethane, a polystyrene, a polybutadiene, or a styrene and butadiene block copolymer.

51. The abrasive rotary tool of any of the preceding embodiments, further comprising an abrasive article, the abrasive article comprising the abrasive external working surface and a base layer coupled to the abrasive external working surface, wherein the base layer has an average thickness of between 1 and 10 mils.

The operation will be further described with regard to the following detailed examples. These examples are offered to further illustrate the various specific and preferred examples and techniques. It should be understood, however, that many variations and modifications may be made while remaining within the scope.

EXAMPLES

Materials

Materials	
Abbreviation or Trade Name	Description
MCD1.5	A 1.5 micron monocrystalline diamond, available from Diamond Innovations, Worthington, Ohio.
MCD2	A 2 micron monocrystalline diamond, available from Diamond Innovations, Worthington, Ohio.

* Particle size is the mean measured by conventional laser light scattering.

Test Methods and Preparation Procedures

Coverglass Production Test-1

A partially-finished coverglass following a scribing operation to form perimeter edges interior features edges, including holes was provided. The partially-finished coverglass was edge ground using a CNC machine to form the desired size and shape. Following the grinding step, the edges were polished to provide a suitable surface finish.

Coverglass Production Test-2

A partially-finished coverglass following a scribing operation to form perimeter edges interior features edges, including holes was provided. The partially-finished coverglass was edge ground using a CNC machine to form the desired size and shape. The edge ground coverglass was then abraded using the CNC machine to improve the surface finish of the ground edges. Following the abrading step, the edges were polished to provide a suitable surface finish.

Table 1 provides a comparison of Coverglass Production Test-1 and Coverglass

Process Step	Test-1 cycle time (seconds)	Test-2 cycle time (seconds)	Ra (nm)	Rz (nm)
Scribe and break glass			—	—
Edge grinding glass to size and shape	NA	NA	551	6581
Polish edges without abrading	240	—	22	2286
Abrade ground edge	—	25	99	1390
Polish edges after abrading	—	60	19	103
Total time	240 seconds	85 seconds	—	—

Abrasive Effectiveness Test

A partially-finished coverglass following a scribing and rough grinding operation was provided. The cover glass material is Gorilla™ glass 3 from Corning™. The partially-finished coverglass was edge ground using a CNC machine to form the desired size and shape. The edge ground coverglass was then abraded using a CNC machine and a cylindrical abrasive tool to improve the surface finish of the ground edges. The surface finish of different diamond abrasive compositions was compared to evaluate the effectiveness of different abrasive compositions.

Table 2 provides a comparison of the different abrasive compositions evaluated using the Abrasive Effectiveness Test.

Sample	Abrasive Diamond Size	Agglomerate Particle Size	Ra (nm)	Material Removed (in 10 min)
A	MCD1.5	30 μm	100	5 mg
B	MCD2	30 μm	175	16 mg
C	MCD2	20 μm	95	15 mg

As shown in Table 2, Sample C provided a much higher level of material removal than Sample A, which had a smaller abrasive size, and about the same level of material removal as Sample B. However, Sample B had high surface finish roughness compared to Sample A and Sample C. According to these results Sample C provides nearly the surface finish quality of Sample A while maintaining nearly the material removal speed of Sample B.

Sample C has a relatively high abrasive size relative to the agglomerate size. In particular, the ratio of abrasive size to agglomerate size for Sample C is 10 to 1. In other examples, a ratio of abrasive size to agglomerate size of no greater than 15 to 1, of no greater than 12.5 to 1, of no greater than 10 to 1, but no less than about 3 to 1, no less and may be likewise particularly useful for edge grinding coverglass.

Various examples of this disclosure have been described. These and other examples are within the scope of the following claims.

Edge Shape Conformity Test

For this test a complex spline shape was used as a target shape and abrasive articles of differing base layers were used to measure the deviation between the finished part and the desired spline shape. The surface roughness (Ra [nm]) of the finished coverglass was measured at 4 equidistant points along the spline surface with a Bruker interferometer for each sample. The incoming coverglass pieces for this test started with roughness of 500-600 nm, so measured values of roughness less than 500 nm represent some effect of the finishing operation, but lower and more consistent values across the 4 equidistant points represents better end result for same process conditions. For this test, the conditions for everything but the base layer were maintained at 4000 rpm, 500 um depth of compression and 30 in/min traverse rate. In each case the abrasive coated base layer was laminated to foam sub layer and then to the aluminum tool core.

Table 3 provides a comparison of measured roughness uniformity across the 4 equidistant points for different base layer materials. For each of these cases a 2 micron diamond was used in equivalent abrasive coating.

Base Layer	Point 1 Ra [nm]	Point 2 Ra [nm]	Point 3 Ra [nm]	Point 4 Ra [nm]	Roughness variation (Max − Min)
PET	220-350	100-130	105-160	150-430	330 nm
Polyurethane	140-240	150-170	140-155	90-210	120 nm

What is claimed is:

1. An abrasive rotary tool comprising:

a tool shank defining an axis of rotation for the rotary tool; and

an abrasive external working surface coupled to the tool shank, wherein the abrasive external working surface comprises:

a resin; and

a plurality of porous ceramic abrasive composites dispersed in the resin, the porous ceramic abrasive composites comprising individual abrasive particles dispersed in a porous ceramic matrix, material, wherein at least a portion of the porous ceramic matrix comprises glassy ceramic wherein a ratio of the average porous ceramic abrasive composite size to the average individual abrasive particle size is no greater than 15 to 1;

wherein the porous ceramic abrasive composites represent between 35 percent to 65 percent by weight of the working surface, based on the total weight of the resin and the porous ceramic abrasive composites.

2. The abrasive rotary tool of claim 1, wherein the resin includes an epoxy resin.

3. The abrasive rotary tool of claim 1, wherein the resin includes one or more of a group consisting of:

a polyester resin;

a polyvinyl butyral (PVB) resin;

an acrylic resin;

thermal plastic resin;

a thermally curable resin;

an ultraviolet light curable resin; and electromagnetic radiation curable resin.

4. The abrasive rotary tool of claim 1, wherein the individual abrasive particles comprise diamond.

5. The abrasive rotary tool of claim 1, wherein the individual abrasive particles include one or more from a group consisting of:

cubic boron nitride; fused aluminum oxide; ceramic aluminum oxide;

heated treated aluminum oxide; silicon carbide; boron carbide; alumina zirconia; iron oxide; ceria; and garnet.

6. The abrasive rotary tool of claim 1, wherein the porous ceramic abrasive composites have an average particle size of less than 65 microns and a max particle size of less than 500 microns.

7. The abrasive rotary tool of claim 1, wherein the porous ceramic matrix comprises a glass including one or more from a group consisting of: aluminum oxide; boron oxide; silicon oxide; magnesium oxide; sodium oxide; manganese oxide; and zinc oxide.

8. The abrasive rotary tool of claim 1, further comprising metal particles dispersed in the resin.

9. The abrasive rotary tool of claim 1, wherein the abrasive external working surface is a molded surface.

10. The abrasive rotary tool of claim 1, wherein the abrasive external working surface forms an arrangement of precisely shaped abrasive agglomerates, each precisely shaped abrasive agglomerate being tapered with diminishing width toward its distal end.

11. The abrasive rotary tool of claim 1, further comprising a flexible planar section positioned opposite the tool shank relative to the cylindrical section,

wherein the flexible planar section forms the abrasive external working surface on a first side of the flexible planar section facing generally away from the tool shank,

wherein the flexible planar section facilitates abrading, with the abrasive external working surface, a corner of the workpiece across multiple angles relative to the axis of rotation for the rotary tool through bending of the flexible planar section when the abrasive external working surface is applied to the corner of the workpiece.

12. The abrasive rotary tool of claim 11,

wherein the abrasive external working surface is a first abrasive external working surface, the abrasive rotary tool further comprising a second abrasive external working surface on a second side of the flexible planar section, the second side of the flexible planar section facing in the general direction of the tool shank,

wherein the corner is a first corner of the workpiece adjacent a first side of the workpiece, and

wherein the flexible planar section facilitates abrading, with the second abrasive external working surface, a second corner adjacent to a second side of the workpiece, the second side of the workpiece opposing the first side of the workpiece, across multiple angles relative to the axis of rotation for the rotary tool through bending of the flexible planar section when the second abrasive working external surface is applied to the second corner of the workpiece.

13. The abrasive rotary tool of claim 1, wherein the abrasive external working surface includes an abrasive cylindrical surface.

14. The abrasive rotary tool of claim 1, wherein the abrasive external working surface surrounds the axis of rotation for the rotary tool, the abrasive external working surface providing one or more circular cross sections perpendicular to the axis of rotation such that tool shape corresponds to a desired finished shape of an edge of the workpiece.

15. The abrasive rotary tool of claim 14, wherein the abrasive external working surface is a first abrasive external working surface, the abrasive rotary tool further comprising a second abrasive external working surface forming an angled surface relative to the axis of rotation for the rotary tool to facilitate abrading interior or exterior beveled edges of the workpiece.

16. The abrasive rotary tool of claim 1, wherein the abrasive external surface forms a planar surface perpendicular with the axis of rotation for the rotary tool.

17. The abrasive rotary tool of claim 1, wherein the abrasive external working surface forms an angled surface relative to the axis of rotation for the rotary tool to facilitate abrading interior or exterior beveled edges of the workpiece.

18. A method of finishing an edge of a partially-finished cover glass for an electronic device, the method comprising:

continuously the rotating abrasive rotary tool of claim 1;

contacting the edge with the abrasive external surface of the continuously rotating abrasive rotary tool to abrade the edge.

19. The abrasive rotary tool of claim 1, further comprising an abrasive article, the abrasive article comprising the abrasive external working surface and a base layer coupled to the abrasive external working surface, wherein the base layer comprises a polyurethane, a polystyrene, a polybutadiene, or a styrene and butadiene block copolymer.

20. An abrasive rotary tool comprising:

a tool shank defining an axis of rotation for the rotary tool; and

an abrasive external working surface coupled to the tool shank, wherein the abrasive external working surface comprises:

a resin; and

a plurality of porous ceramic abrasive composites dispersed in the resin, the porous ceramic abrasive composites comprising individual abrasive particles dispersed in a porous ceramic matrix, material, wherein at least a portion of the porous ceramic matrix comprises glassy ceramic wherein a ratio of the average porous ceramic abrasive composite size to the average individual abrasive particle size is no greater than 15 to 1;

wherein the abrasive external working surface forms an arrangement of precisely shaped abrasive agglomerates, each precisely shaped abrasive agglomerate being tapered with diminishing width toward its distal end.

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